Principles of Orthopaedic Surgery



A beautiful example of dynamic posture from the Second Book of *De Humani Corporis Fabrica* by Andreas Vesalius, Basel, 1543. (Reproduced from Heinrich Palmaz Leveling, Ingolstadt, 1783.)

Principles of ORTHOPAEDIC SURGERY

Revised Edition

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To my daughters
ALICE and MARY

Preface

The father of orthopaedic surgery was Nicholas André (1658–1742), Professor of Medicine at the University of Paris, who in his two volume book *L'orthopédie ou l'art de prévenir et de corriger dans les enfants difformités du corps*, published in Paris in 1741, coined the term "orthopaedia" by combining the two Greek words *orthos* and *paidios*, which freely translated mean "to straighten the crooked child."

Sir Arthur Keith, in 1919, described it as a branch of medicine whose purpose was "to effect the repair of the mechanical framework of the human body by all operations and appliances which have that aim in view."

Today the scope of this specialty has been greatly broadened and at present it is concerned with the physiologic function of the musculoskeletal system as well as the preventior correction and investigation of injuries, diseases and anomalies of this system. Its many problems require correlation of the skills of the clinician, the pathologist, the radiologist, the biochemist, the physiologist, the physicist and the physical therapist in the rehabilitation of the child and adult.

This book is an outgrowth of my teaching orthopaedic surgery at the University of Pennsylvania and is an expansion and further development of *Regional Orthopaedic Surgery*, published in 1950. It is in large part a reflection of my personal experiences, and if it succeeds in being of help to the general practitioner as well as to the specialist in bone and joint surgery, its purpose will have been achieved. The increase of traumatic disabilities in the population at large has made it desirable in this new revised volume to place emphasis on trauma as well as on the chronic conditions ordinarily included in the term "orthopaedic surgery."

Many of the illustrations are contributed by members of the Orthopaedic Staff of the University of Pennsylvania and some of the cuts have been borrowed from other books. All of these I here gratefully acknowledge.

In the chapter on shoulder disabilities, I especially owe a vote of

thanks for criticism and revision to James A. Dickson, M.D., my friend of many years. Also, I wish to thank my friends for their helpful suggestions and would be especially remiss not to mention the following assistance: Roy I. Peck, M.D., on the bone tumor section; Edgar L. Ralston, M.D., on scoliosis problems, and Z. B. Friedenberg, M.D., on wrist and hand disabilities; also my appreciation to Robert H. Cram, M.D., and Erwin R. Schmidt, M.D., for the collection of helpful photographs.

To the publishers, I am grateful for their patience and friendly cooperation in the preparation of this volume, and especially to Mr. H. P. Hall and Mrs. Mary Rackliffe, whose critical analysis has enabled me to bring the book to publication with many less faults than would have otherwise been possible.

P. C. C.

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1

Physiology of the Bones and Joints

THE DEVELOPMENT OF BONE

In the osseous system those bones that develop within cartilage arise by means of enchondral development, and those which are not preceded by cartilage but are produced within sheets of connective tissue are of intramembranous origin, arising directly from the mesenchymal cells.

Enchondral development: All the bones of the extremities, the spinal column and the thorax, the auditory ossicles, the hyoid bone and the greater part of the bones of the base of the skull.

Intramembranous: The bones of the face and the greater part of the vault of the skull.

Both enchondral and intramembranous: Certain of the skull bones.

In growth zones of cartilage, proliferation followed by degeneration is constantly occurring, especially at the growing ends of the diaphyses, providing an increase in the diameter of a bone and also longitudinal growth along the pattern of the individual bone. Microscopically (Fig. 1) one can observe thick bands of proliferative cartilage cells forming a coarse network; and as the cells undergo degeneration the matrix, when stained with hematoxylin, can be seen to contain large amounts of calcium. The osteoblasts on the diaphyseal side are in an active proliferative state, creeping over the framework of the matrix and remaining after cartilage degeneration. It can be noted that the most active zone of long bone growth is at the periphery of the epiphyseal plate area.

remodeling of the bone which occurs in normally growing bone and the tenaciousness with which Nature reproduces the pattern of the individual bone whose contour has been changed through infection or disease are striking features of the osseous system; for these reasons bone must not be considered as an inert substance but one that responds rapidly to the stresses and strains to which it is subjected. Wolff's law states that both the internal structure and external form of living bone change with every alteration of function (Ollier, from Keith). Not only does the bone grow in length, but also in thickness; in order that the growing bone maintain its tubular structure, the expanded ends must be subjected to a process of absorption and consolidation, which Jansen (1928) called "tubulation" and which seems to be accomplished largely by the osteoclasts. In the roentgenograms of healing fractures we can see not only this tubulation, but also the speed of callus deposition and absorption.

Undifferentiated embryonic connective tissue is found in early fetal life, and through this is scattered a meshwork of fibrillae in which large fibroblasts are found. This connective tissue matrix is adapted to all types of morphologic changes, such as its development into fibrous tissue when the fibrillae become prominent; or, when invaded by blood vessels, it may be transformed into hemopoietic tissue. In the calcifying tissue of what is later bone we find the fibrillae, the bone cells and the matrix, which develop into three types of bone — the embryonic, the spongy and the compact. Embryonic bone in the young is imperfect bone tissue, which may become transformed into *compact bone,* which develops into the hard cortical bone which the Haversian canals traverse; or *cancellous bone,* containing the marrow cavity.

Compact Bone

When a cross section of compact bone is prepared, the Haversian canals are noted as minute spaces in the center of the Haversian system (Fig. 2). The contents of these canals are a tiny artery and vein, plus lymphatic and areolar tissue.

Surrounding this canal are five to ten concentric parallel lamellae and between these layers are small irregular spaces, *lacunae,* which enclose a bone cell. These cells are stellate masses of protoplasm with

In fetal life the diaphys[illegible] center portion of which almost always appear before birth [illegible] manifest in the clavicle at the sixth week *in utero*, are [illegible] primary centers" of ossification. As a rule the "secon[illegible] [illegible]," which are the epiphyseal portions, are formed after birth. [illegible] [illegible]nyses of the vertebral column are the last to fuse, occurring at about the twenty-fifth year of life.



FIGURE 1. The cartilaginous epiphyseal end of a radius from a 6-week-old dog. *A*, ossification center. *B*, zone where multiplication and orderly arrangements of cell columns take place. *C*, zone where hypertrophic and degenerating cartilage cells are observed. *D*, zone of capillary invasion (zone of provisional calcification). *E*, metaphyseal end of the diaphysis. In this zone, one observes the process of new bone formation. Bone matrix is deposited on the remaining calcified cartilage trabeculae. (× 143. Hematoxylin and eosin.) (Scudder, C. L. *The Treatment of Fractures.* Philadelphia, W. B. Saunders Co., 1938.)

The skeletal system is derived from the mesoderm and has a twofold function: (1) It serves as a rigid framework to which are attached the muscles and ligaments of the body that give stability and mobility to the animated machine; and (2) it acts as a reservoir or

and Moore (1928), may have the property of laying down new bone or of absorbing existing bone, their function depending upon the requirements in the given area. Certain investigators assign to these cells the ability to form osteoid tissue and also to aid in the production of phosphatase.

Also, between each Haversian system are scattered lacunae and canaliculi which act as a communicating system in this compact bone. On the marrow side is a lining membrane, the endosteum, which resembles somewhat the periosteum.

Cancellous Bone

The spongy or cancellous bone is particularly rich in osteogenic activity and is found in the *flat bones,* such as the ribs and sternum; in such *irregular bones* as the ilium; and makes up the bulk of the ends of the *long bones.* The marrow is reddish in color instead of the yellowish color which is characteristic of the midshaft area. The marrow contains much less fat than the midshaft area and has a coarse fibrillar structure of connective tissue with lacunae and canaliculi, but without the Haversian system of compact bone.

This spongy bone has a great field of usefulness in hastening bone repair. It is easily obtained from the ilium and may be packed about the edges of a bone graft as (1) bone chips in cases of delayed and nonunion of the long bones, (2) to aid in bone healing after various types of joint arthrodeses, or (3) for packing bone cavities.

Periosteum

In the fetus, compact or cortical bone is surrounded by a layer of embryonic connective tissue which in early fetal life is the perichondrium and later becomes the periosteum. On the inner surface of the periosteum are found layers of the young bone element, which Ollier (1919) called the osteogenic or *cambium* layer. Leriche and Policard (Key and Moore, 1928), however, do not find in these cells any features distinguishing them from the young connective cells, but regard the periosteum as composed of an outer loose connective tissue layer and an inner layer made up of solid fibrous bundles and elastic fibers.

The periosteum is the conducting medium for the blood vessels passing to the outer cortical surface of the bone, but the major portion of the diaphyseal circulation is supplied by the nutrient artery after it divides in the marrow cavity of the bone. The periosteum contains,

a number of processes extending out from the lacunar spaces into the *canaliculi,* these spider-web processes communicating one with another; those lacunae nearest the Haversian canal communicate with it and probably serve to maintain bone nutrition. Whether the cells occupying the lacunar spaces should be classified as osteoblasts has given rise to a great deal of discussion. These cells, according to Key



FIGURE 2. Haversian system. Cross section through human bone. (× 360.) (Weinmann and Sicher, *Bone and Bones.* C. V. Mosby Co., 1955.)

rivet-like down from the periosteum into the cortex, the so-called *fibers of Sharpey*.

Owing to its juxtaposition to the outer surface of the cortex, the periosteum may be stripped up by injury or disease and then become a site for ossification. Under such stimuli it becomes congested, and the fibrous envelope reverts to its embryonic state with the ability to develop bone.

There are two mutually antagonistic processes of bone remodeling constantly active from birth until death. This steady phenomena of bone resorption and formation can be disturbed by nutritional, hormonal, mechanical or vascular causes.

Joints

The size and shape of a joint surface will give evidence of the amount and type of motion present in that particular joint. The articular surfaces are covered by a *hyaline variety* of cartilage which is thickened in the areas of greatest pressure. The capsule is made up of an outer fibrous and an inner synovial layer. The ligaments which bind and stabilize the joint are strong bands of white fibrous tissue closely connected to the periosteum of the bone. At least two types of ligaments are present at any joint: (1) the capsular ligament which encloses the synovial membrane; and (2) individual thickenings of the capsular ligament occurring at the points of stress and strain, which by their strength serve to hold the bones together and allow controlled freedom of motion.

Metabolism

It has been estimated that in the adult man perhaps less than 1 per cent of the calcium of the body is accessible, so that the labile fractions of bone are very small in comparison with the stable fractions of bone, whose ions are not available for interchange.

Bone is essentially a modified connective tissue and in recent investigations with the electron microscope it is seen to be composed of three parts, i.e., an organic matrix, collagen fibers and an interfibrillar cement substance, upon which are deposited mineral elements. The bone cells can be shown to surround themselves with a coating or matrix, which holds tiny crystals of calcium and phosphorus taken up from the blood stream. These crystals not only add to the hardness of the bone, but actually serve as a reservoir for the storage of calcium

in addition to the blood vessels, nerve fibers which regulate the vasomotor function. The fibrous layer of the periosteum does not normally have any specific osteogenetic function, although this was a debatable point for years. It would seem that during the growth period the cambium, or inner layer of the periosteum, and in adult life the subperiosteal

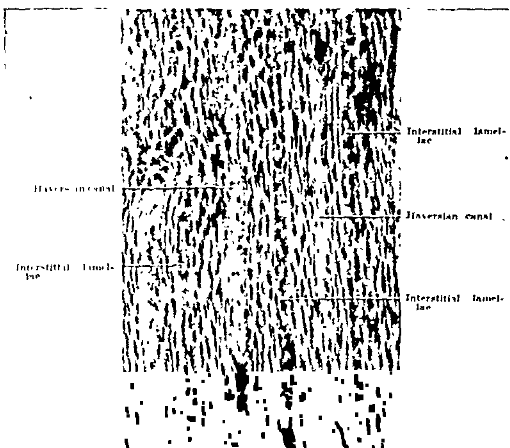


FIGURE 3. Haversian systems. Longitudinal section through human bone. (× 120; reduced to ¾.) (Weinmann and Sicher, *Bone and Bones* C. V. Mosby Co., 1955)

osteoblasts have a definite osteogenetic property, increasing the width of the bone by normal growth These cells play an important role in the healing of fractures.

On the outer layer of compact bone are large channels, *Volkmann's canals*, running at right angles to the periosteal surface, which communicate with the Haversian canals (Fig. 3) and convey blood vessels into the diaphysis and epiphysis. The periosteum is further kept in close contact with the underlying bone by fibrous strands extending

ample, the knee joint). The fringes or synovial villi are found especially around the margin of the articular surfaces; these contain loops of capillary blood vessels. These synovial villi vary greatly in size and shape and are composed of connective tissue resembling the part of the capsule from which they arise. The synovial membrane is derived from the mesenchyme and has both a secretory and an absorptive property (Kling, 1938).



FIGURE 4. Areolar type of synovial membrane showing folds (villi), from the lateral capsule of the knee joint of a man 51 years of age. (8 mm. objective and ocular 8.) (Cowdry, *Special Cytology, Vol. II.* Paul B. Hoeber, Inc., 1924.)

There must be the ability both to supply nutrition to the joint and to remove waste products from the joint cavity. Effusions must reach the cavity by means of filtration from the blood vessels. It has been shown that after ingestion of glucose a prompt rise of sugar in a knee joint effusion will occur. Diffusible substances reach the cavity with different speeds.

and phosphorus. Some investigators, such as Robinson and Elliot (1957), believe that during calcification the water-soaked matrix loses its water content and is replaced by tiny crystals of calcium and phosphorus, so that the most fully calcified osteoid tissue has the least power of interchanging calcium and phosphorus ions. If this is true, the body is thereby robbed of a large part of its mineral pool, and in some areas of compact bone no fluid is available to transport minerals to and from bone. Sometimes compact bone, even though containing mineral ions, is not accessible to the body fluids. But the dynamic nature of bone metabolism is a well-known fact and calcium is being continually removed and replaced. With the recent introduction of tracer radioactive elements it has been possible to appreciate the distribution and movement of phosphate and calcium ions in the normal bone metabolism.

The skeleton, being the reservoir of 99 per cent of the calcium and almost 90 per cent of the phosphorus in the body, has a very important role in regulating the mineral content in the soft tissues, which contain less than 0.7 grains of calcium. This minute quantity in the blood and body fluids normally is remarkably well kept in balance: calcium is added to the blood by absorption from food or breakdown from bone tissue and is lost by excretion in sweat, urine and feces, or by deposition in newly formed bone, and in health remains quite constant at 10 to 11 mg. per 100 cc. But the parathyroid glands can apparently act as a thermostat, raising the level of blood calcium when parathyroid extract is injected intravenously.

Plasma phosphorus regulation is as important as that of calcium and is essential for cell metabolism. If there is an absence of phosphorus in the diet, the mineral will be mobilized from the skeleton to maintain the soft tissue level; and then the bones become flexible and soft and death may result. The serum inorganic phosphorus is normally 2.5 to 4 mg. per 100 cc.

The blood serum protein has a normal figure between 6.5 Gm. and 8 Gm. per 100 cc., and if it falls below this level, the rate of repair of the body tissues is very definitely delayed.

Synovial Membrane

The synovial membrane, lining the joint cavities, consists of loose connective tissue with elastic fibers. In the larger joints the membrane is thrown into redundant folds (Fig. 4) which project into the joint space and sometimes may enclose masses of adipose tissue (for ex-

FACTORS PRODUCING ABNORMAL BONE GROWTH

In the normal development of long bones as well as in injuries and infections of the joints, the epiphyses always play a very important role before they become fused. Any changes involving the bone ends will produce impairment of joint function (Table 1).

TABLE 1

APPEARANCE AND OSSIFICATION OF THE EPIPHYSES
(From Scudder: *Fractures*)

Epiphysis	*Appears*	*Completely Ossifies*
Upper humeral	7 weeks	19–20 years
Internal epicondyle	As early as 7 years, not constantly present till 11 years	15–17 years
External epicondyle	Not ordinarily as separate epiphysis	15–17 years
Capitellum	Seventeenth month	15–17 years
Trochlear	As early as eighth year, not constantly present till eleventh year	15–17 years
Head of radius	Occasionally at 5 years, constant at 7 years	13–14 years
Olecranon	Eighth year	14 years
Distal radial	6 months	20–21 years
Distal ulnar	6–7 years	20–21 years
Head of femur	Second half of first year	15–16 years
Greater trochanter	5 years	15–16 years
Lesser trochanter	9–11 years	15–16 years
Lower femoral	Present at birth	19 years
Upper tibia	Present at birth	19 years
Upper fibula	About fifth year	15–18 years
Lower tibia	5 months	18 years
Lower fibula	13 months	18 years

In any discussion of osseous growth and repair, the behavior of the epiphyses during normal growth and their response to normal and abnormal conditions are valuable to note. Few epiphyseal centers of the long bones are present at birth or at known periods in gestation and many others become visible through the roentgenogram after birth. The long bones increase in thickness by ossification of the deeper layers of the periosteum and increase in length by cell activity in and about the epiphyseal plate region, later, bone growth ceasing at the epiphyseal areas when the epiphyses become fused with the diaphyses by bony union. Certain individual bone ends grow normally much more rapidly than others. For instance, 65 to 70 per cent of the growth of the lower

Absorption is very rapid, chiefly through the blood vessels, as has been shown many times by injecting potassium iodide, sodium iodide or dyes into the knee joints of animals. The process of absorption has been hastened by joint inflammation; and not only has the local injection of an antibiotic to combat pyarthrosis proved locally beneficial, but systemically the rapid absorption may be of great value in combating septicemia.

Experimental data would indicate that the metabolism of articular cartilage is very low and that the nutritional requirements are minimal.

The structure and function, therefore, of the synovial membrane is both secretory and absorptive, and the dual function is apparently possessed by different areas of the membrane.

In response to trauma or disease the joint may be distended by hemorrhage or exudate, and in addition the increased cell activity will produce large amounts of synovial mucin. Under these conditions the synovial membrane becomes thickened, and the extent of the subsequent reaction of the synovial membrane and its villi depends upon the severity of the injury or disease.

Synovial Fluid (Synovia)

Normally the synovial fluid is straw-colored, sticky and of viscous character, resembling the white of an egg, its stickiness being due to the mucinous substance produced by the synovial cells. It consists of 94 per cent water, certain salts, proteins and mucin, with oil drops and the remains of cells displaced by injury or disease (Kling, 1938). It functions as a lubricant to the joint and as a nutrient to the articular cartilage. In normal synovial fluid a microscopic examination will show the fluid to be almost free from tissue debris and to have an extremely low leukocyte count — between 10 and 50 cells per cubic millimeter. The high alkalinity of the normal synovia is thought to be due to the rich supply of capillaries, which secure rapid exchange between the blood stream and the synovial membrane.

It should be emphasized that there is a marked difference between the composition of the synovial fluid in the normal joint and in the diseased joint. Aspiration of joint effusion may be of great value in diagnosis; such factors as quantity, turbidity, viscosity, precipitation, cell count, Wassermann reaction and reactions to complement-fixation tests may establish or confirm the diagnosis in disease.

TABLE 2 (continued)

Age	Weight				Stature			
	Mean		Standard Deviation		Mean		Standard Deviation	
	lbs.	kg.	lbs.	kg.	in.	cm.	in.	cm.
			FEMALE					
Months								
3	12.6	5.7	2.43	1.10	23.6	59.9	1.24	3.14
6	16.5	7.5	2.27	1.03	25.9	65.9	1.09	2.78
9	19.2	8.7	2.25	1.02	27.7	70.3	1.07	2.71
12	21.2	9.6	2.54	1.15	29.3	74.4	1.04	2.64
15	23.4	10.6	2.31	1.05	30.8	78.2	.96	2.43
18	24.9	11.3	2.29	1.04	32.4	82.2	.94	2.39
21	26.0	11.8	2.49	1.13	33.5	85.0	1.04	2.65
24	27.1	12.3	2.71	1.23	34.2	86.9	1.09	2.78
27	28.0	12.7	2.95	1.34	35.1	89.2	1.04	2.65
30	29.3	13.3	3.09	1.40	36.0	91.5	1.18	2.99
33	30.6	13.9	3.28	1.49	36.8	93.5	1.24	3.16
36	32.0	14.5	3.22	1.46	37.6	95.6	1.27	3.23
42	34.4	15.6	3.73	1.69	38.9	98.9	1.49	3.78
48	36 6	16.6	3.79	1.72	40.4	102.5	1.49	3.78
Years								
4.5	37.5	17.0	4.96	2.25	41.1	104.4	2.06	5.23
5.5	41.8	19.0	5.98	2.71	43.7	110.9	2.15	5.47
6.5	46.5	21.1	6.86	3.11	46.0	116.8	2.18	5.53
7.5	51.5	23.4	8.00	3.63	48.1	112.2	2.24	5.69
8.5	57.1	25.9	9.39	4.26	50.3	127.7	2.39	6.07
9.5	63.1	28.6	11.06	5.02	52.2	132.7	2.48	6.29
10.5	70.2	31.8	12.91	5.86	54.4	138.2	2.62	6.65
11.5	78.8	35.7	15.01	6.81	56.7	144.1	2.89	7.34
12.5	89.1	40.4	17.01	7.72	59.1	150.1	2.94	7.47
13.5	98.9	44.9	17.18	7.79	61.0	155.0	2.66	6.75
14.5	106.2	48.2	15.98	7.25	62.2	157.9	2.42	6.14
15.5	114.2	51.8	15.03	6.82	63.2	160.5	2.28	5.78
16.5	116.7	52.9	14.73	6.68	63.4	161.1	2.26	5.74
17.5	117.5	53.3	15.05	6.82	63.4	161.1	2.34	5.94

extremity occurs about the knee region. Age at epiphyseal fusion can be so closely estimated from the different bones that we can conclude whether they are occurring within normal limits or not (Table 2).

TABLE 2

STATURE AND WEIGHT OF CHILDREN FROM BIRTH TO SEVENTEEN YEARS OF AGE

	Weight				*Stature*			
Age	*Mean*		*Standard Deviation*		*Mean*		*Standard Deviation*	
	lbs.	*kg.*	*lbs.*	*kg.*	*in.*	*cm.*	*in.*	*cm.*
				MALE				
Months								
3	12.7	5.7	1.98	.90	24.4	62.0	.83	2.10
6	17.0	7.7	2.49	1.13	26.9	68.3	1.06	2.70
9	20.1	9.1	2.71	1.23	28.7	72.8	1.11	2.83
12	22.4	10.2	2.65	1.20	30.1	76.5	1.10	2.80
15	24.7	11.2	2.82	1.28	31.5	80.0	1.08	2.75
18	26.5	12.0	2.87	1.30	32.7	83.0	1.18	3.00
21	28.0	12.7	2 98	1.35	33.8	85.8	1.16	2.95
24	29.3	13.3	3.09	1.40	34.8	88.3	1.22	3.10
27	30.6	13.9	3.09	1.40	35.6	90.3	1.36	3.45
30	31.7	14.4	3.20	1.45	36.3	92.3	1.30	3.32
33	32.8	14 9	3.09	1.40	37.1	94.3	1.31	3.33
36	33.7	15 3	3.31	1.50	37.9	96.3	1.26	3.20
42	35.7	16.2	3.42	1.55	39.4	100.0	1.38	3.50
48	37.7	17.1	3.64	1.65	40.7	103.5	1.57	4.00
Years								
4.5	38.6	17.5	4.81	2.18	41.0	104.1	2.10	5.34
5.5	43.2	19.6	5.85	2.65	44.1	111 9	2.19	5.57
6.5	47 8	21.7	6.39	2.90	46 4	117.8	2.16	5.48
7.5	52.6	23.9	7.12	3.23	48.5	123.3	2.22	5 63
8.5	58.3	26 4	8 71	3.95	50.7	128.7	2.39	6.06
9.5	64.3	29.2	9.70	4.40	52.7	133.8	2.45	6.22
10.5	70 4	31.9	11.48	5.21	54.5	138.5	2.56	6.50
11.5	76 9	34.9	12.95	5.87	56.3	143.0	2.67	6 78
12.5	84.9	38.5	15.54	7.04	58 3	148.2	2.93	7.44
13.5	95.1	43.1	17 83	8.09	60.7	154.1	3.29	8 35
14.5	106.9	48.5	19.85	9.00	63.1	160.3	3.43	8.71
15.5	123.4	56.0	20.02	9.08	66 1	167.8	3.10	7.88
16.5	133.2	60 4	19.23	8.72	67.6	171.7	2.79	7.08
17.5	139.2	63.1	18 49	8.39	68.4	173.8	2.56	6 49

cartilage plate is a real barrier to the extension of these infections, as they only rarely penetrate the plate. Pyogenic osteomyelitis and tuberculosis are much more likely to reach the joint cavity by burrowing peripherally than they are to penetrate the plate. In those cases in which the metaphysis is entirely intra-articular, as in the hip, the spread of the infection is likely to produce pyarthrosis; whereas in those in which the epiphyseal plate is extra-articular, the pus will seek the surface of the bone by infiltrating the Haversian canals, burrowing under and stripping up the periosteum, sometimes even rupturing to the surface and forming a sinus. Frequently, late bone growth complications may follow osteomyelitis in the long bones. The growth center can be so interfered with that a deformity of the joint surface may even occur.

Sometimes there will be stimulation of growth resulting in increased bone length, but more frequently one will find cessation of bone growth, or one portion of the epiphyseal plate will continue to grow and another cease, producing joint deformity. We may occasionally see a tuberculous process which involves the diaphysis, the epiphyseal plate, and the epiphysis; if such an area of bone destruction (crossing the epiphyseal plate) is visualized in the roentgenograms, one should suspect a tuberculous lesion.

In addition to the infections mentioned above, those involving the central nervous system, such as infantile paralysis, can produce a disturbance of normal bone growth. There are, of course, other factors besides the virus of poliomyelitis which affect the central nervous system. One of these is edema, producing extensive interference with the circulation and giving rise to paralysis of one or more groups of muscles, thus causing a loss of normal function. However, as Harris and McDonald (1936) have shown, many of these paralytic extremities can be stimulated to an increase in length by improving the circulation through sympathectomy.

Debilitating diseases. Another cause of disturbances in and about growth centers, but fortunately not often giving rise to any severe deforming growth disturbance, is severe illness during childhood. One can often detect small transverse sclerotic lines at varying levels near the diaphyses which appear to represent a period in the child's life at which some general illness produced disturbance of normal bone growth. One can frequently ascertain the existence of these lines when studying the bone in a routine examination.

Trauma. This is another cause of disturbance of the epiphyseal

The "primary center" of the long bone appears quite early in fetal life, the clavicle being the first to ossify. Only in three instances does the "secondary center" or epiphysis appear before birth: in the lower end of the femur, the head of the tibia and occasionally the head of the humerus. Epiphyses may arise from a single center (nucleus), as in the lower end of the femur, or from several, as in the upper end of the humerus. Parsons (1923) has divided the epiphyses into three types: (1) those which he terms "pressure epiphyses," which simply transfer the weight of the body from bone to bone and form the majority of the joints; (2) those which appear as knoblike processes which are concerned with the pull of the muscles, as in the trochanteric area, and are called "traction epiphyses"; and (3) the "atavistic epiphyses," such as the tuberosity of the ischium, which represents a portion of the skeleton that in the early structure of the skeletal system was of functional importance.

The relationship of epiphyseal growth to bone growth was recognized as early as 1867 by Ollier (1899). It is of interest to note that the epiphysis toward which the nutrient artery of the bone is directed is the first to be united with the shaft. The periosteal vessels are the main sources of blood supply to the epiphyseal plate and form anastomoses with the terminal branches of the nutrient artery. These cartilage plates are very interesting areas in the bone, and their normal and regular development may be interfered with by a variety of conditions. There are certain clinical observations which make one suspect that these epiphyseal plates are far more active in growth at their peripheries than towards their centers.

Acquired Conditions

Under this heading lies the largest number of causes of limb inequalities. The most frequent cause of shortening is infantile paralysis. Occasionally patients with osteomyelitis or joint tuberculosis will show some local stimulation of bone growth, or, if the epiphyseal plate is involved, there may be a retardation of growth. In a great majority of femoral fractures in childhood, even when accurately reduced, there will be a temporary slight longitudinal growth increase, but in a few years the length of the legs will assume their normal relationship. If there has been extensive overriding of the shaft with shortening in malunion, an epiphyseal arrest on the opposite side may be necessary.

Infection. Early evidence of infection in the long bones usually consists of areas of necrosis and liquefaction in the metaphyseal area. The

Occasionally there will be a congenital shortening of one of the lower extremities of such degree as to give rise to a secondary postural or functional spinal curvature. If the shortening is not more than 3 inches, it can usually be corrected when the child is 8 to 9 years of age by an epiphyseal arrest on the sound side, or in an adult by a femoral shaft shortening operation. Methods of leg lengthening are not in common use today, for there are many postoperative complications that make it a rather hazardous procedure.

In addition to these clear-cut causes of epiphyseal growth disturbance, a large group are due to defective development in the process of endochondral ossification. In this grouping belong the achondroplasias and the dyschondroplasias. Ollier (1899) described the type of case called dyschondroplasia as "a bone growth disturbance often limited to one side of the body, irregular in its distribution, and affecting particularly the ulna and fibula." It is often called Ollier's disease.

Another osteochondral growth disturbance is chondrodystrophia foetalis or achondroplasia. This is characterized by a long trunk with both the upper and lower extremities disproportionately shortened and presenting a large head on the dwarflike figure. There is no satisfactory treatment for these conditions resulting from defective endochondral ossification. Occasionally, for cosmetic purposes, some of the irregular bony masses may be surgically removed, or the epiphysis in Ollier's disease on the unaffected side may be closed surgically in order to slowly correct some of the disproportion.

METHODS OF MEASURING AND AFFECTING BONE GROWTH

Measurement

Roentgenograms supply more accurate data than a tape measure regarding bone length, while the use of the teleogram and the scanogram are the most accurate. However, for practical follow-up purposes the flexible steel tape marked in centimeters and inches is commonly used, and is quite accurate if recorded at regular intervals by exactly the same method and examiner. In order to determine the exact measurement of the long bones by roentgenograms, it is important to have records preceding and following an epiphyseal-arrest procedure or limb-shortening operation.

Teleoroentgenogram: It has been estimated that if the tube is 72

growth. In this connection, we are beginning to have increased respect for those cases of so-called "sprained" joints in the growing period. At times they may represent major or minor slipping of the epiphysis, or longitudinal epiphyseal fracture with or without attached bone fragments. These may even show no roentgenographic change whatsoever, but the trauma may be sufficient to cause epiphyseal disturbances of growth to develop later.

The late Clay Ray Murray vigorously called attention many times to the potential danger of sprains in children, pointing out that the term was often an entirely inadequate description, for it gave a false sense of security to the parents of these children. In a child, any joint which has suffered severe trauma, either with or without roentgen evidence of fracture or epiphyseal injury, should have roentgengrams taken a few months later to determine the possibility of any growth disturbance.

Deficiencies. The deformities of bone growth are illustrated in one of the nutritional diseases of childhood fortunately rarely seen today: active rickets. Here the epiphyseal cartilages are thicker and more vascular, with irregularity in the size and shape of the columns of distorted cartilage cells. The zone of calcification is ill defined and the periosteum is much thickened. In these softened bones, deformities easily occur. The prevention and correction of deformity is both a pediatric and an orthopaedic problem.

Tumors. Cases of delayed or increased bone development in childhood due to endocrine disturbance are occasionally seen, such as thyroid deficiency (giving rise to cretinism) or pituitary hyperactivity (giving rise to gigantism).

Bone tumors which arise close to the epiphyseal plate may occasionally give rise to growth disturbance.

Congenital Abnormalities

Congenital shortening of one extremity, or absence of one or more bones, is occasionally seen as an example of disturbance of bone growth. Small inequalities of ⅛ to ¼ inch in the lower extremity are frequently congenital, and only occasionally give rise to any symptoms or require any treatment. Variations of more than ½ inch are a secondary cause of low back pain. If the inequality is not more than ½ inch the shortening preferably should be corrected by shoe alterations The best way is to remove ¼ inch from the heel of one shoe and add ¼ inch to the heel of the other.

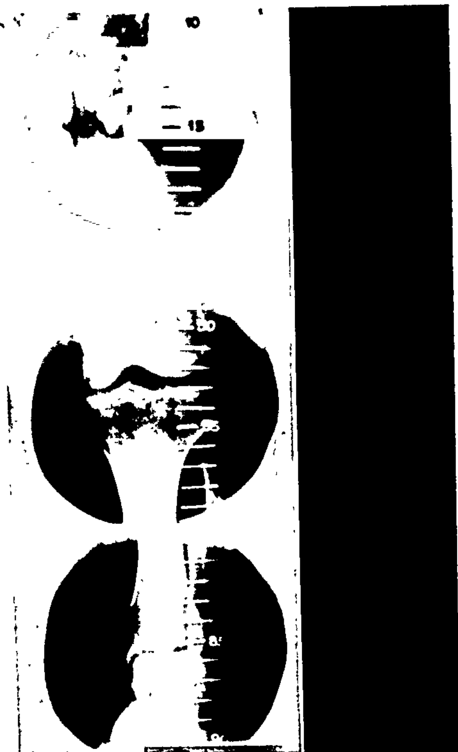


FIGURE 5. Spot scanogram of femur and portion of meter stick with lead markers one centimeter apart.

which measurements will be taken. If, for instance, the apex of the greater trochanter of the femur is a measurement point, the rule and the trochanter should be superimposed. If, however, the uppermost point of the femoral head is to be a measurement point, that point and the rule should be superimposed.

inches away from the part to be recorded, a silhouette without distortion will be made, giving approximately the length of the bone.

Slit scanogram: This was introduced by Milwee (1937), and consists of a regular roentgenographic plate with a side rail and arm to hold the tube at a film target distance of 25 inches. An adjustable slit is arranged between the tube and the patient, and as the tube is driven by a motor along the table at varying speeds, a beam of roentgen ray passes through the slit and traverses the patient. This reduces the effects of distortion and variation of density and gives an accurate roentgenogram.

Spot scanogram: The following method of spot scanography is employed at the University of Pennsylvania Hospital:

A 7 by 17 inch cassette is divided into three sections. The Bucky diaphragm is used. A meter ruler with known spaced lead numbers embedded in the wood is placed over the midline of the table, and fastened securely. The patient is then placed supine and is positioned so that the hip joint, the knee joint and the ankle joint are directly over the midline of the table and meter ruler. A very small cylinder is used at a distance of 36 inches so that there is no overlapping of the exposed area. The hip joint is carefully centered to the upper third of the cassette and the tube is aligned to this.

In like manner, without moving the patient, the knee joint is centered to the center section and the ankle joint to the lower third of the cassette.

A detailed description of this method has been kindly furnished me by Dr. Paul Eyler, radiologist, as follows:

> Accurate measurement of the length of long bones can readily be accomplished by the use of an ordinary meter stick to which certain simple alterations have been made. The meter stick is drilled along its edge at each centimeter marking. Ordinary straight pins are then driven into each hole and the heads clipped off flush with the surface. The meter stick is then turned on its flat side and, with a router bit, a flat-bottomed pit is made at each 5 cm. mark. Small lead numerals are placed in each pit and fastened with plastic wood or other plastic cement.
>
> A radiograph of a portion of the altered meter stick appears on the accompanying illustration (Fig. 5).
>
> The measurement of the length of a long bone can be accomplished by making films with most any diagnostic X-ray machine, although a fluoroscope with a spot film device offers certain advantages. The meter stick is attached to the extremity by adhesive tape, so that it cannot move in relation to the extremity during the measuring procedure The meter stick should lie either immediately over or under the points from

still going on, and the problem of local stimulation is far from solved, though temporary stimulation may follow fracture of the shaft or even the removal of bone grafts.

Methods of Arresting Epiphyseal Growth

Certain methods have been advocated for arresting the rate of growth in the long bones preceding the time of normal epiphyseal fusion.

This approach to the problem of equalizing limb length dates largely from the noteworthy work of Phemister (1933) (Fig. 6) and consists

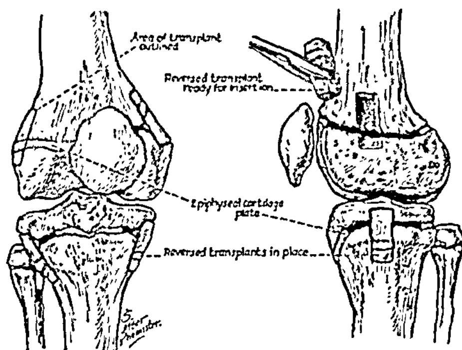


FIGURE 6. Phemister technic of epiphyseal arrest. Transplants reversed and cartilage chiseled out of epiphyseal plate. (Redrawn from Phemister, D. B. *J. Bone & Joint Surg.*, 15; from Campbell, W. C. *Operative Orthopaedics*, edited by Speed and Knight, St. Louis, C. V. Mosby Co., 1956.)

of surgically producing a fusion of the epiphysis to the diaphysis in any of the long bones of the upper or lower extremity. An epiphysiodesis on the normal side is done and is so calculated that the length of the two sides will be approximately equal when maturity is reached. *It is suitable only for children over 8 years of age who have a growth expectancy of a few years.* Many technics have been advocated and many methods of calculating expected growth from a given epiphyseal growth chart have been made. The numerous factors that normally influence bone growth make a completely accurate statistical chart diffi-

The accuracy of the method depends upon the central ray passing through the rule and the point chosen for measurement. Thus the radiographic image is recorded without distortion due to angulation of the rays.

Fluoroscopic location of the rule and the measurement points is advantageous. In many instances films may be very readily made on the spot film device of the fluoroscope. If the films are made in the Bucky tray, a long cylinder cone should be used on the X-ray tube. Thus exposures of several measurement points may be made on a single film without the need for lead shielding of various portions of the film.

Analysis of problems relating to inequality of length of long bones frequently calls upon this method of measurement. In addition, it is frequently employed to predetermine the proper length of intramedullary metallic fixation devices in femoral shaft fractures. In many of these instances the films are made at the bedside with the mobile X-ray apparatus. Sometimes, for convenience, the measurements are made on the unfractured femur rather than on the fractured one.

Estimates of the diameter of the medullary canal are best made from films of the fractured bone rather than from its uninjured mate. One can roughly figure that the width of the medullary canal is magnified about 10 per cent on the usual roentgenogram.

Normal Epiphyseal Growth

Certain general facts can be kept in mind regarding the rate of normal epiphyseal growth. It is estimated that in the lower extremity alone, 40 per cent of growth occurs in the lower and about 10 per cent in the upper femoral epiphysis; while about 30 per cent of growth occurs in the upper and about 20 per cent in the lower tibial epiphysis. White and Warner (1938) have found that following the arrest of the lower femoral epiphysis, ⅜ inch per year shortening may be anticipated. If the upper tibial and fibular epiphyses are fused, ¼ inch shortening per year plus ¼ inch for fusion of the lower fibula and tibial epiphyses may be expected, making a total of ⅞ inch per year. Very little longitudinal growth occurs at the upper femoral epiphysis. These figures are usually subject to slight individual differences.

Methods of Stimulating Epiphyseal Growth

Based on the fact that an increase in the blood flow to a bone stimulates its growth, lumbar sympathectomy has been advocated for moderate discrepancies in limb length. It has been used most frequently on the postparalytic child Gains in length up to 1.5 inches have been reported by Harris and McDonald (1936). Local stimulation of growth of long bones has been produced by Pease (1952) by inserting ivory pegs in the region of the lower femoral epiphyseal plate as well as in the subadjacent upper tibial epiphysis. Investigations are

the experimental stage of development, but may prove to be clinically useful (Harris and McDonald, 1936).

The growth chart (Fig. 8) of Green and Anderson (1947) is especially helpful for consultation before any of these operations are done.

CENTIMETERS OF CORRECTION TO BE DERIVED
FROM ARREST OF DISTAL FEMUR OR PROXIMAL TIBIA
PRELIMINARY CHART, 1947

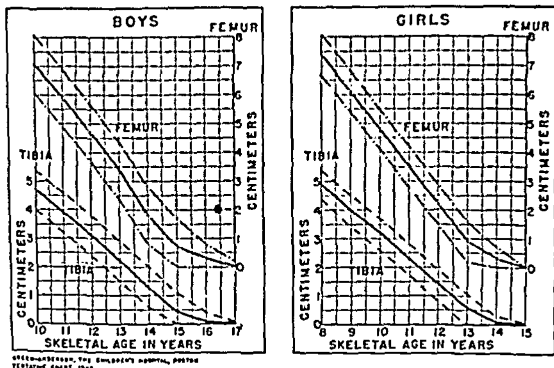


FIGURE 8. From these tables prepared by Green and Anderson, amount of growth to be eliminated after epiphyseal arrest can be estimated. Central line represents average correction; secondary lines, the useful range. Extremes are not indicated. (From Green, W. T., and Anderson, M. *J. Bone & Joint Surg.*, **29**, taken from Campbell, W. C. *Operative Orthopaedics*, edited by Speed and Knight. St. Louis, C. V. Mosby Co., 1956.)

MUSCULOSKELETAL SYSTEM EXAMINATION OF PATIENT

A large number of orthopaedic patients are children. Therefore, calmness and gentleness on the part of the physician will often permit the desired information to be obtained with the minimum amount of time and effort. Gaining the confidence of the patient early in the examination is indispensable if an accurate evaluation of a sensitive joint is to be made. It is not easy to obtain this co-operation in a terrified infant or young child.

cult, although several are reasonably satisfactory. The parents' skeletal conformation, the patient's skeletal age as compared with the chronological age, the normal spurt or retardations of skeletal growth which may be affected by the patient's health and climatic conditions are all at times determining factors in the individual case.

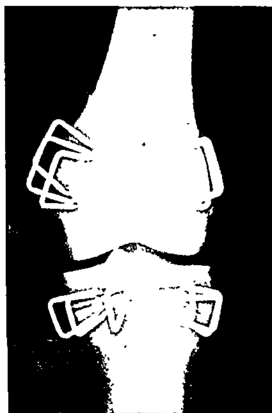


FIGURE 7. Blount staples inserted to delay epiphyseal growth of femur and tibia at knee region. The upper fibular epiphysis was curetted

In the last few years an effort has been made to employ methods that insure temporary epiphyseal arrest. Haas (1945) used wire loops fastening the epiphysis to the diaphysis; and Blount and Clarke (1949) have advocated using this principle of compression of the epiphyseal plate by employing staples driven into the diaphysis and epiphysis (Fig. 7), bridging the epiphyseal plate area. Both methods bid fair to be of great practical value in stopping epiphyseal growth for limited periods of time. There is a good deal of accumulated data to substantiate the belief that growth will be resumed on removal of these compressing forces and will continue until bone maturity. The use of carefully screened roentgen rays over the epiphyseal plate area is in

any unusual feature of the affected extremity. The normal contour of the spine and its flexibility under activity can be observed by asking the child to walk toward its parents, or to stoop to pick up some familiar object from the floor. In the mind of the examiner this question must always be answered: "Is there any pain, deformity or limitation of motion on active and/or passive movement?"

Joint Examination. Often orthopaedic surgery deals with mechanical disabilities which are self-evident on inspection. The active and passive movements of the joint and region involved are all too frequently studied only casually. In addition to the general systemic examination of the patient, attention must be focused on the individual part affected to determine its underlying disease state.

Whether the joint is held in a deformed attitude, whether its movements are being guarded by accompanying muscle spasm and/or intra-articular disease, and whether there is redness, swelling, atrophy and other evidence of disease or injury may be determined by *inspection* and *palpation.*

The palm and fingers of the examiner should be placed flatly and snugly against the affected area while active and/or passive movements are being accomplished. In this way, local heat, tenderness, crepitus, intra-articular or periarticular swelling may be detected; a torn or displaced muscle, an internal joint derangement or muscle spasm resulting from joint irritation may be discovered. The patient should then be requested to move actively the affected part or parts of all suspected joints through the full range of painless movement. Then the examiner should carefully determine whether there is a further range of passive motion by manually carrying the limb gently through any further arc of movement. Only when a normal range of active, painless motion is present can the joint be regarded as normal.

Restriction of motion may be due to an extra-articular or intra-articular lesion. Pain on movement in every direction indicates an inflammatory lesion *in the joint* or in the part intimately connected with the joint. Freedom of movement in one or more directions, but not in all, usually suggests a lesion involving some of the *extra-articular* structures.

Muscle atrophy occurs very early in the course of joint injury or disease. Disuse of the part only partially explains this phenomenon. In inflammatory joint lesions, muscle spasm produces muscle atrophy; in poliomyelitis, muscle atrophy is the result of both disuse and muscle

The examination should be conducted along certain definite lines, and by establishing a routine examination, which can be expanded or curtailed as the individual problems arise, much valuable time can be saved and essential data obtained.

First, the age, sex, weight and occupation of the patient are recorded; any or all of these points may aid in the diagnosis.

History

After the initial phase of the interview, the patient or parent is questioned carefully regarding the onset of the disability. To arrange logically the history of events and their relation to the complaint of the patient is both a science and an art. Accurate history-taking from the parent or, if possible, the patient, should be done, but the questions must be phrased carefully in order to prevent the patient from becoming unnecessarily worried. Not only should the family history and past history be obtained, but the present illness and previous treatment must be minutely reviewed and evaluated.

Is there a definite history of injury or illness? If so, *where, when and how did it occur?* Was the onset of the present condition gradual or sudden? Have there been recurrences? Many times the simple question "When was the patient last perfectly well?" will provoke a most informative answer. The type and duration of previous treatment and present illness should be investigated Careful attention should be paid to evidence of any foci of infection. Is there a possible familial or congenital type of lesion present? Many further questions should suggest themselves as the interview proceeds.

Physical Examination

After the history is taken and recorded and a *general physical examination* made, it is most essential that the orthopaedic adolescent or adult patient be so draped as to permit a thorough examination of the body as a whole: the build and posture as well as active and passive joint function. He must be placed in a good light in order that as many facts as possible may be gleaned from inspection.

It is advisable to have young children perfectly naked. The child's attention should be directed toward the presence of objects with which he is familiar, for in this way his natural postures may be observed. Inspection will reveal the general shape and body contour of the child, as well as any gross evidence of deformity. A limp can be most easily detected under these circumstances, as well as shortening, atrophy, or

real length of the extremity in contrast to the measurement taken from the umbilicus to the internal malleolus, which is described as the *apparent length.* These lengths will be affected if either hip joint has a fixed deformity such as flexion, adduction or abduction. The sound

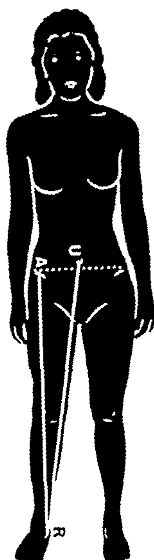


FIGURE 9. Measurements for length of lower extremities *RA* = Anterior superior spine to internal malleolus. *RU* = Umbilicus to internal malleolus. If the hip joint motions are not free but are fixed in any position with flexion, adduction, etc., the sound limb must be measured in this same position to avoid inaccuracies.

side must be placed in the same degree of deformity as the opposite hip, which may be fixed in adduction, abduction or flexion, if an accurate reading of the affected side is to be obtained. Therefore, when one hip joint is fixed in abduction, either by bony or fibrous ankylosis, the affected limb is *apparently* (not really) longer, and the normal side only *apparently* shorter.

To accurately measure bone length see pages 19–22.

spasm. At times atrophy may develop very rapidly. It is particularly striking in the quadriceps femoris with lesions of the knee joint.

Measurements. Since orthopaedic surgery deals largely with joint function and abnormalities of the bones, careful measuring and recording of limb length and circumference, as well as joint function, is essential at the primary examination. A definite system of measuring should be employed. All measurements must be kept with the patient's record, to serve as progress notes. A goniometer, for measuring joint angles, as well as a flexible steel or cloth tape marked in both inches and centimeters, for measuring length and circumference, must be available.

In measuring the range of joint function, full extension is regarded as the "angle of greatest extension" (A.G.E.), and full flexion as the "angle of greatest flexion" (A.G.F.). Often normal joint function is not present, being restricted by soft tissue contraction, bony block or both. In these instances the restriction may be limited in range or all joint motion lost, due to the underlying disease. If intra-articular in origin, we may have a "fibrous ankylosis" (a jog of motion) or "bony ankylosis" (solid fusion of the joint). For convenience of recording these measurements briefly, the range of motion is recorded by a goniometer, or an estimation of joint angles can be accurately made by an experienced observer. One hundred and eighty degrees is accepted as representing full extension of a joint, and from this base line are subtracted the degrees of the angle representing the restriction of joint function. Therefore, if the elbow joint lacks 30 degrees of normal extension and can be flexed only to 90 degrees, the joint function is recorded as follows: A.G.E. = 150 degrees, A.G.F. = 90 degrees. This is a convenient way of stating that this joint has a 60-degree range of motion within the arc of normal motion, that it demonstrates no extension beyond 150 degrees and has a restriction of flexion to 90 degrees.

In all tape measurements, bony landmarks must be employed as the fixed points. One must be certain that the pelvis is level before beginning length measurement in the lower extremities. To establish this, examine the patient on a firm table; when the pelvis is level, an imaginary line connecting the anterior superior spines should cross at right angles another line connecting the xiphoid cartilage and the symphysis. To determine the length of the lower limbs, measurements should be taken from the anterior superior spine of the ilium to the tip of the internal malleolus on each side (Fig. 9). This reveals the

tears in various regions of the body this method of positioning joints can be of great value in orthopaedic surgery.



FIGURE 10. Acromioclavicular relaxation demonstrated by suspending weight in hand on affected side.

One may make use of this method by recording supine and standing lateral views in chronic *lumbrosacral strains* which present an increased lumbosacral angle. Often increased movement at the lumbosacral joint can be demonstrated, indicating an area of instability. Another use of this method is in the postoperative evaluation of *idiopathic scoliosis* by lateral bending films. After spine fusions it is sometimes very difficult or impossible to clinically decide whether a fusion operation has resulted in actual bony union. If we routinely take two lateral bending films, bending to right and then to left, and one with the spine extended and another in the flexion position (four views), conclusive evidence regarding the integrity of the previous operation may be obtained. If pseudoarthrosis is present, motion which is not evident in the routine films will be readily proven by this method. Again, relaxation or disease at the sacroiliac joint may be corroborated when the symphysis pubis shows excess mobility, as described by Chamberlain (1930).

In the hip the push and pull roentgenograms or the abduction and adduction roentgenograms are of aid in deciding a suspected case of *delayed union or nonunion,* and we can also demonstrate frank nonunion more clearly by these methods.

Laboratory Data

Routine blood counts and urine examinations are needed. In the various bone dyscrasias it may be desirable to have blood determinations of the calcium, phosphorus and acid and alkaline phosphatase. In cases of delayed tissue repair, whether of the soft tissues or of the osseous system, the serum protein should be determined. Other laboratory data must be assembled as it appears to be related to the problem presented.

Roentgenograms

Roentgenograms, like all other laboratory aids, are extremely valuable, but one must not adopt the habit of relying only upon them for the diagnosis. Roentgenograms are confirmatory in character, and should never take the place of a thorough clinical examination. The habit to be acquired is that of carefully examining the patient first, then analyzing the roentgenograms and other laboratory data in relation to the problem.

One must, however, be impressed with the advantage of utilizing by roentgenogram what has been called the "functional test" in increasing our information regarding cases presenting disability of the bones and joints By this method, one can graphically illustrate the range of normal and abnormal skeletal motion that can be produced. We all utilize movement in roentgenology in the daily use of the fluoroscope; but in the osseous system the concept of a rigid, bony framework has often caused the overlooking of valuable data which could be elicited from the roentgenogram.

In pathologic states involving the bones and joints, there are a number of conditions in which excessive mobility can be demonstrated. This may be accomplished by exerting force manually on the affected joint, thereby demonstrating an appreciable amount of joint displacement, such as in acromioclavicular dislocation; and demonstrating unusual relaxation of joint structures about the knee and other joints by holding the limb in one position for one film and demonstrating relaxation by another film (Fig. 10).

A graphic record of this mobility may be obtained to aid in diagnosis and subsequent treatment. The extent and variety of bone and joint lesions in which this principle can be utilized will depend largely on both the ingenuity and the close co-operation between the roentgenologist and the othopaedic surgeon. In ligamentous relaxations and

testings is obvious and will result in a more consistent grading. It will help to avoid the errors that arise from different positioning and undue pressure during the examination, as well as detecting substitution movements when spotty muscle weakness is present.

Legg and Merrill (1932) published a description of muscle grading based on the method devised by Dr. Robert W. Lovett (1917) and known as the Lovett system. This uses gravity resistance for grading muscle strength, outlined as follows:

Z — Zero. No contraction in muscle can be felt.
T — Trace. Muscle can be felt to tighten, but cannot produce movement.
P — Poor. Muscle produces movement with gravity eliminated, but cannot function against gravity.
F — Fair. Muscle can raise part against gravity.
G — Good. Muscle can raise part against outside resistance as well as against gravity.
N — Normal. Muscle can overcome a greater amount of resistance than a "good muscle."

Muscle Testing Techniques

Figures 11–59 are from Daniels, L., Williams, M., and Worthington, C. *Muscle Testing.* Philadelphia: W. B. Saunders Co., 1947.

Neck

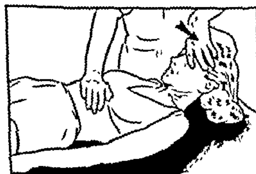


Fig. 11.

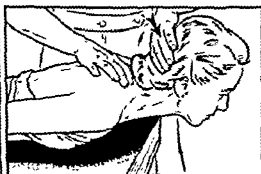


Fig. 12.

FIGURE 11. Flexion of neck against resistance demonstrates chiefly the strength of the sternocleidomastoid muscles.
FIGURE 12. Extension of neck against resistance demonstrates chiefly the power of the trapezius and longissimus capitis and cervicis muscles.

At the ankle, certain injuries of one or both bones of the leg near the ankle may result in an abnormal separation of the tibia and fibula at their lower ends, and this can be demonstrated by various positionings of the foot.

At the wrist this method is particularly helpful in ruling out the question of a fracture of one of the carpal bones or ascertaining the degree of healing following a fracture of one of these bones, so that not only should the anteroposterior and lateral views, but always the oblique view, be requested. At times a view of the hand in both dorsal flexion and plantar flexion will aid greatly in the diagnosis of the *suspected scaphoid* fracture or help in identifying the extent of bony repair present.

Of course the same principle is true in many congenital deformities, particularly *dislocation of the hip*, where the degree of soft tissue relaxation can so strikingly be demonstrated by push and pull roentgenograms.

Muscle Testing Charts

The methods of utilizing muscle function tests are so special that these examinations are illustrated by drawings which have been used freely from the excellent monograph on *Muscle Testing* by Daniels, Williams and Worthingham (1956). Descriptive legends have been inserted, and it is to be noted that the patient's muscle contraction is made against the resistance of the examiner's hand which is employing force in the direction of the arrow.

Muscle testing is a very important phase of physical diagnosis and also is an aid to prognosis and treatment in many neurosurgical conditions involving both the central nervous system and the peripheral nerves.

These diagrams of muscle function tests outline a method of examination for the regional muscles with normal strength. When they are weakened or paralyzed, their impairment affects their capacity to carry the normal load of stresses and strains. This means that the examiner must be prepared to modify the tests somewhat, depending upon the strength of the muscle groups being examined.

Careful examinations repeated at fixed intervals give a good index of the rate of recovery in a weakened muscle or in a muscle that has been transposed to substitute for an impaired one, but a thorough knowledge of both the anatomy and function of the normal muscle is essential. The benefit of having the same examiner give the repeat

Hip

Fig. 17.

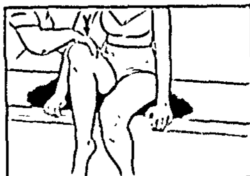
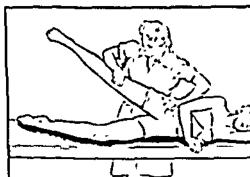
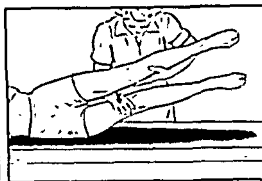


Fig. 18.



Fig. 19.





Fig

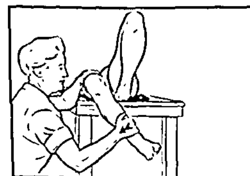


Fig. 21.

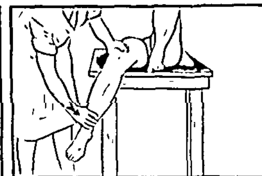


Fig. 22.

FIGURE 17. Flexion of hip. Method of testing power of iliopsoas muscle.
FIGURE 18. Extension of hip. Method of testing power of gluteus maximus and hamstring muscles.
FIGURE 19. Abduction of hip. Method of testing power of gluteus medius and minimus muscles.
FIGURE 20. Adduction of hip. Method of testing power of right adductor magnus, longus, brevis and pectineus muscles.
FIGURE 21. External rotation of hip. Method of testing power of all the muscles inserted into the digital fossa of the femur (obturator, internus and externus, quadratus femoris, pyriformis, gemellus, superior and inferior).
FIGURE 22. Internal rotation of hip. Method of testing power of gluteus minimus and tensor fascia latae muscles by having patient internally rotate the thigh against resistance.

Trunk

Fig. 13.



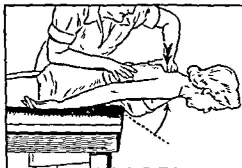




Fig 14. Fig. 15.

FIGURE 13. Flexion of trunk demonstrates chiefly the strength of the recti abdominis muscles

FIGURE 14. Extension of trunk of thoracic and lumbar spine areas shows power of sacrospinalis muscles

FIGURE 15. Rotation of trunk to the right and left. Method of testing power of external and internal oblique muscles.

Pelvis

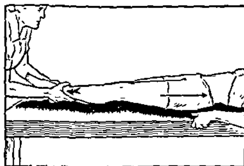


FIGURE 16. Elevation of pelvis. Method of testing power of left quadratus lumborum muscle is shown by having patient elevate the pelvis while counter traction is applied to the left ankle.

Foot



Fig. 27.



Fig. 28.

FIGURE 27. Eversion of foot. Method of testing power of peroneus longus and peroneus brevis muscles.
FIGURE 28. Inversion of foot. Method of testing power of tibialis, anterior and posterior muscles.

Toes

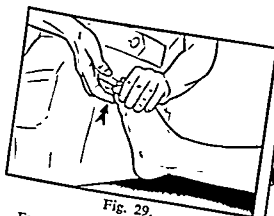


Fig. 29.

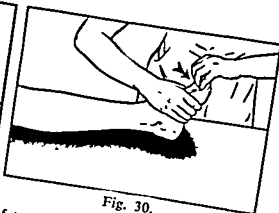


Fig. 30.

FIGURE 29. Flexion of toes. Method of testing power in the flexors of the toes.
FIGURE 30. Extension of toes. Method of testing power in the extensors of the toes.

Knee

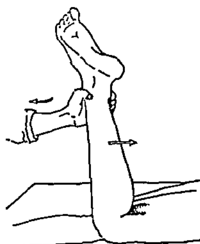


Fig. 23.

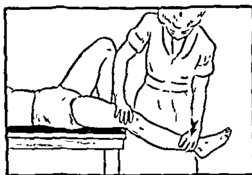


Fig. 24.

FIGURE 23. Flexion of knee. Method of testing power of hamstring muscles (inner and outer).
FIGURE 24. Extension of knee. Method of testing power of quadriceps muscle.

Ankle

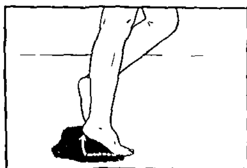


Fig 25.

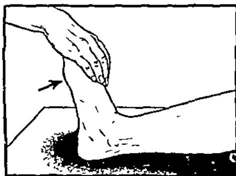


Fig. 26.

FIGURE 25. Plantar flexion of ankle. Method of testing power of posterior group of leg muscles
FIGURE 26 Dorsiflexion of ankle. Method of testing power of anterior group of leg muscles.

Shoulder

Fig. 36.

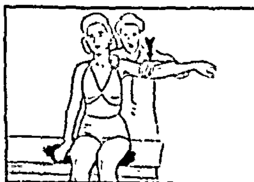


Fig. 37.

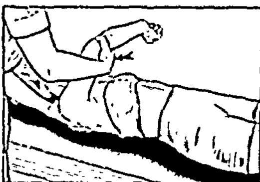


Fig. 38.



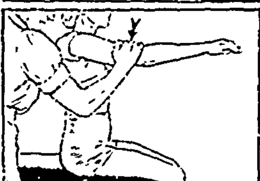


Fig. 39.

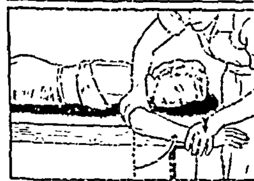


Fig. 40.

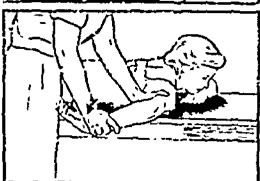


Fig. 41.

FIGURE 36. Abduction of shoulder. Method of testing power of deltoid middle fibers and supraspinatus muscle.

FIGURE 37. Adduction of shoulder. Method of testing power of pectoralis major muscle.

FIGURE 38 Extension of shoulder Method of testing power of latissimus dorsi and teres major muscles

FIGURE 39. Flexion of shoulder. Method of testing power of anterior fibers of deltoid and coracobrachialis muscles

FIGURE 40 External rotation of shoulder. Method of testing power of infraspinatus and teres minor muscles.

FIGURE 41. Internal rotation of shoulder. Method of testing power of subscapularis muscle.

Scapula

Fig. 31.

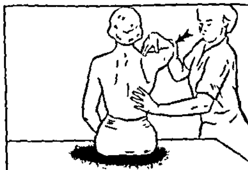


Fig. 32

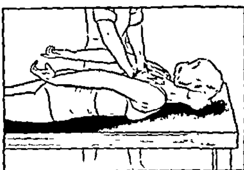


Fig. 33.

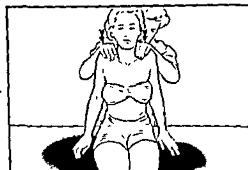
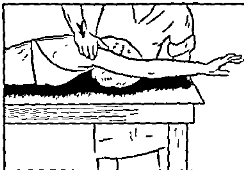


Fig. 34.



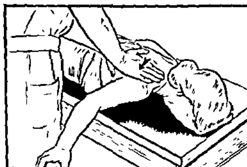
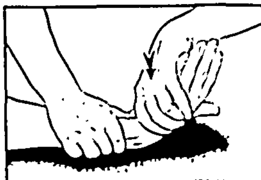


Fig. 35.

FIGURE 31 Abduction and upward rotation of scapula. Method of testing power of the serratus anterior muscle
FIGURE 32. Adduction and downward rotation of scapula. Method of testing power of rhomboideus major and minor muscles.
FIGURE 33. Elevation of scapula Method of testing scapula elevation and power of trapezius (upper fibers) and levator scapulae muscles
FIGURE 34. Depression and adduction of scapula Method of testing power of lower fibers of trapezius muscle.
FIGURE 35. Adduction of scapula Method of testing middle fibers of trapezius muscle.

Wrist

Fig. 46.



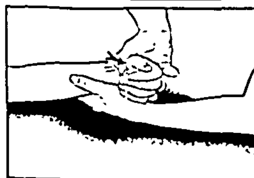


Fig. 47.

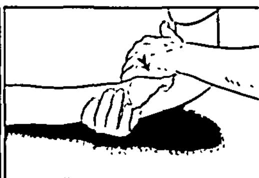


Fig. 48.

FIGURE 46. Flexion of wrist. Method of testing power of flexor carpi ulnaris muscle.

FIGURE 47. Flexion of wrist. Method of testing power of flexor carpi radialis muscle.

FIGURE 48. Extension of wrist. Method of testing power of extensor carpi radialis longus and brevis and the common extensor muscles.

Elbow

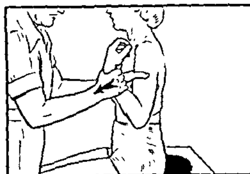


Fig. 42.

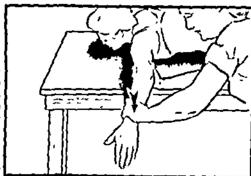


Fig. 43.

FIGURE 42. Flexion of elbow. Method of testing power of biceps and brachialis muscles.
FIGURE 43. Extension of elbow. Method of testing power of triceps muscle.

Forearm

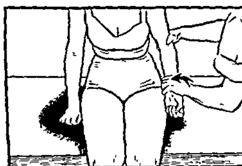


Fig. 44.

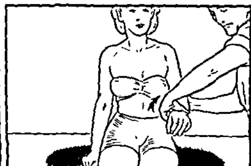


Fig. 45.

FIGURE 44 Supination of forearm. Method of testing power of biceps brachii and supinator brevis muscles.
FIGURE 45. Pronation of forearm Method of testing power of pronator radii teres and pronator quadratus muscles In Figures 44 and 45 the elbow is held at right angles.

Fingers

Fig. 54.

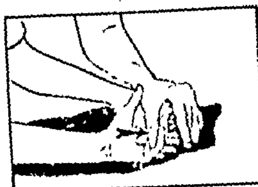
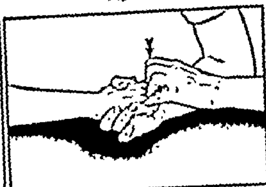


Fig. 55.



56.



Fig. 57





Fig. 58.

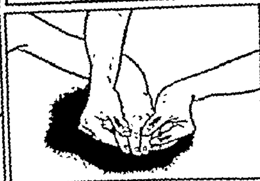


Fig. 59.

FIGURE 54. Flexion of fingers at metacarpophalangeal joints. Method of testing power of the lumbricales, and the dorsal and volar interossei muscles.
FIGURE 55. Extension of fingers at metacarpophalangeal joints. Method of testing power of extensor digitorum communis, extensor indicis proprius, extensor digiti quinti proprius muscles.
FIGURE 56. Flexion of fingers. Method of testing power of flexor digitorum sublimis and flexor digitorum profundus muscles.
FIGURE 57. Extension of fingers. Method of testing power of extensor communis digitorum muscle and interossei muscles.
FIGURE 58. Abduction of fingers. Method of testing power of abductor digiti quinti and dorsal interossei muscles.
FIGURE 59. Adduction of fingers. Method of testing power of palmar interossei muscles.

Thumb

Fig. 49.

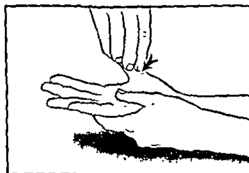


Fig. 50.

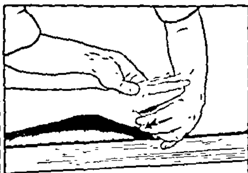


Fig 51

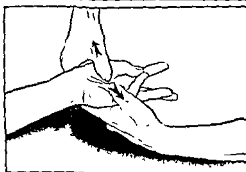
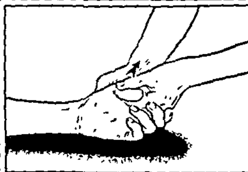


Fig. 52



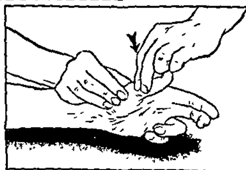


Fig 53.

FIGURE 49. Abduction of thumb Method of testing power of the abductor pollicis longus and brevis muscles
FIGURE 50. Adduction of thumb Method of testing power of adductor pollicis muscle (obliquus and transversus)
FIGURE 51 Opposition of thumb and fifth finger Method of testing power of opponens pollicis and opponens digiti quinti muscles
FIGURE 52. Flexion of thumb Method of testing power of flexor pollicis longus and brevis muscles
FIGURE 53. Extension of thumb Method of testing power of extensor pollicis longus and brevis muscles

2

Pathology of Bones and Joints

Diseases

TUBERCULOSIS

Tuberculosis is a chronic infectious disease produced by the tubercle bacillus, which is capable of attacking practically every tissue in the body. In approximately one-fourth of the cases, an inherited predisposition to tuberculosis has been found to be direct and positive, but in many cases the family history is indefinite.

Formerly, tuberculosis was largely a milk-borne infection in the United States, but this is no longer true. The tubercle bacilli usually enter the body via the respiratory and alimentary tracts. In the great majority of individuals who apparently have been in perfect health, evidence of tubercular infection of the bronchial and mesenteric lymph glands will be revealed at autopsy. Crowded, ill-ventilated living quarters as well as sedentary occupations predispose to the disease through the inhalation of the dried, powdered, infected sputum. Latent tuberculosis will occasionally become active. Injury is a factor favoring activity of the tubercle bacillus. It is of interest in this connection to note the great preponderance of this disease in the lower extremity over that of the upper. It is most common in children during the active growth period, the great majority of these patients being under 14. The disease is rare in children under 2, most of the cases occurring in those between 3 and 5. The joints most frequently affected are: vertebrae, hip, knee, ankle, elbow, shoulder and wrist, in that order.

Tuberculosis is a systemic disease, but the definite help supplied by streptomycin plus para-aminosalicylic acid (PAS) or by the use of

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strangling of the underlying viable tissue, at times resulting in collapse and destruction of the mechanism of the joint. The articular cartilages of the joints are particularly resistant to the tubercle bacillus; although in a tuberculous joint the subchondral area of the joint surface may

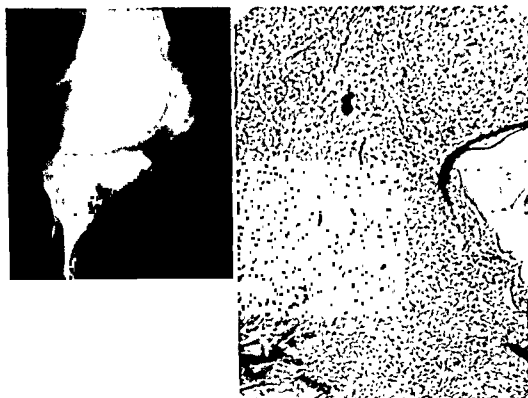


FIGURE 60. Tuberculosis of the knee. *Left*, bone atrophy of the tibia and femur and bone destruction of the articular surfaces. *Right*, microscopic picture of same area. Note tubercles scattered through the section.

become destroyed and the articular cartilage completely loosened from its attachments; the latter area may often be found intact or lying partially "floating" in the joint. The tuberculous material may slowly find its way to the surface, producing sinuses through and under the surrounding muscles and fascia. Caseous material may be discharged from these sinuses. The abscess may heal by calcification or become secondarily infected along its sinus tracts. Whenever the disease is a rapidly progressing one, the skin over the lesion becomes reddened, suggestive of a suppurative lesion, but usually the process is slow, and a gradual roughening of the joint surface will develop with increasing limitation of motion but with very little reddening of the skin. Nature's effort at healing inside the joint may produce a fibrosis which replaces the bone destroyed by the disease. In the spine, when caseation has advanced far enough, the softened bodies of the

isoniazid may allow a re-evaluation of the prognosis. These drugs produce a far less gloomy prognosis in regard to eradication of the disease and restoration of joint function. The encouraging results are thought to be produced by a capillary dilatation around, but not through, the necrotic tuberculous area.

Pathology. There are three definite types of tubercle bacilli: (1) the human, (2) the bovine and (3) the avian. In the United States the human type is most frequent, and in Scotland the bovine type, while the avian is rarely found. However, each type produces approximately the same pathologic reaction in the tissues.

In bone and joint tuberculosis, a great percentage of the patients show no evidence of active pulmonary lesions, either by clinical examination or by roentgenogram. As in other types of osteomyelitis, the local joint disease begins most commonly in the metaphyses because of the abundance of capillaries in this region. Also, bone injury is more frequent at these sites. Although the local activity apparently may be initiated by injury, the disease is almost always secondary to a quiescent tuberculous lesion elsewhere in the body — in children generally in the lymph glands, and in adults in the lungs. It is primarily a systemic disease, and the bacilli may be carried by the blood stream to any part of the body. In bone and joint tuberculosis the characteristic pathologic feature is that of bone destruction with little tendency toward bone production. The disease, starting in the ends of the bones (Fig. 60), follows by gradual extension along the lines of least resistance, and usually involves the adjacent joint. Primary synovial tuberculosis does occur, but joint tuberculosis is usually secondary to the underlying bone disease.

The tubercle bacilli and the epithelioid cells with their surrounding leukocytic ring constitute the visible minute grayish "tubercle." As there are no blood vessels in the tubercle, the local tissue is deprived of nourishment. As a result, coagulative necrosis or caseation occurs, and, by the formation of new tubercles and caseation in the center of the diseased area, an abscess forms. This abscess usually invades the adjacent joint or burrows along muscle planes, often pointing some distance from the affected joint. The abscess consists of a wall of granulation tissue, large or small sequestra, and a varying amount of watery fluid derived from the serum and degenerated leukocytes. The sequestra and degenerated leukocytes give a flaky appearance to the exudate. The joint becomes lined by a tuberculous granulation tissue or "pannus." Irregular erosions of the joint surfaces occur, due to

called "night cries." This is particularly frequent in tuberculous spondylitis (Pott's disease).

Limitation in motion is a very early and constant sign in chronic inflammatory joint disease and varies in degree with the underlying pathologic state. A limp or awkwardness in walking can be noted best with the patient stripped and walking in good light. Any irregularities of gait may be discovered by this method. Disinclination to activity is often an early symptom of joint disease. Muscle spasm is a constant factor producing limitation of motion. Normal motion must be evaluated by examining the opposite joint and then comparing it with the affected one, for the range of painless motion present must be carefully evaluated if the patient is to be properly treated.

Muscle atrophy about the superficial joints can be observed early in bone and joint tuberculosis; although other signs must always be looked for in the well-padded muscular joints, such as the hip and spine; it can be seen very early in tuberculosis of the knee joint.

Deformity of the part, or an attitude in which the patient instinctively holds the limb to protect it against sudden jars or strains, is also an early sign of joint disease. The limb is pulled into this attitude by muscle spasm, the position assumed being determined by the strength of the opposing muscle groups. In hip joint disease, a flexion and adduction deformity is produced. At the wrist, since the flexor muscles are stronger than the extensors, the hand is pulled into the flexed wrist attitude. Later, shortening of the limb on the affected side commonly occurs, because in chronic disease there is some retardation of growth through inactivity, and also because the destruction is intra-articular. However, the disease may occasionally stimulate bone growth by continued hyperemia, resulting in lengthening of the limb. This is especially true in tuberculous disease of the shaft of the long bones.

Diagnosis. Although the family history is of some importance, examination of the patient will usually suffice to make the diagnosis. Elevation of the temperature in the afternoon is quite characteristic of the disease. The von Pirquet skin test, the tuberculin test, the Mantoux test and the patch test are all valuable diagnostic aids. A positive reaction with any of these in a child under 6 is strong evidence of the existence of active tuberculosis, while a negative tuberculin test in children and young adults is strong presumptive evidence against tuberculosis. In the majority of cases, the systemic examination as well as examination of the local joint affected will make the diagnosis possible. The physician must always be alert to multiple osseous le-

vertebrae collapse, producing the well-known angular deformity *kyphos* or *gibbus*.

Caries sicca is a dry type of bone and joint tuberculosis. It most frequently involves the shoulder and elbow and has little tendency toward abscess and sinus formation, but it does produce typical bone destruction without bone production.

Rice bodies have been thought to be only characteristic of tuberculosis, but they may be occasionally found in other types of chronic joint irritation, particularly in the flexor tendon sheaths of the wrist, as well as in tuberculous tendon sheaths and bursa. They can often be diagnosed by palpation. They are composed entirely of fibrous tissue and consist of dozens of small rice-sized bodies, probably formed by small bits of synovial tabs that have gradually been deprived of their circulation so that they drop off into the joint, bursa or tendon sheath.

Other loose bodies are formed by proliferation of the synovial membrane and have been designated *lipoma arborescens*. These bodies are found in the synovial type of any arthritis, and very little evidence exists to indicate that they are characteristic of a tuberculous joint.

Clinical Picture. The clinical symptoms in the tuberculous type and nontuberculous type of bone infection occasionally may not be essentially different, although in any joint in which tuberculosis is suspected, *chronicity* of the symptoms in a youthful patient favors the diagnosis of tuberculosis.

Swelling in the joint occurs early and can be detected by inspection and palpation. After the synovial membrane becomes involved in the process, it gradually thickens and when the joint is examined, the tissues are found to be thickened and boggy. In the joint most easily examined, the knee, the part is found to have lost its normal contour. These tuberculous joints become limited in motion with the formation of intra-articular adhesions or a "barley-water" type of synovitis. As the effusion disappears, the remaining swelling is tense and elastic; the joint has a thick, doughy feeling and is fusiform in outline.

Pain is not a constant symptom although frequently present. Attempted motion will cause pain. Extensive joint destruction may precede the symptom of local pain in spinal disease, but pain may be referred to an adjacent joint. Frequently in hip joint disease, the patient complains of pain about the knee This is worse at night or when relaxation of the muscle spasm that has protected the part subsides, allowing the destroyed joint surfaces to rub against one another, which in turn causes a reflex muscle spasm and gives rise to the so-

jacent surfaces of the muscle and fascia. The fluid content is thin and watery, with tiny fragments of serum, leukocytes, fibrin and masses of degenerative tissue suspended in it. It usually is whitish in color, although in the later stages of suppuration it has a yellowish appearance. The abscess may perforate the skin by one or more openings and discharge its contents, or it may burrow beneath the soft tissues for long distances before reaching the surface as a fluctuant abscess. Calcified abscesses are recognized by their roentgenogram shadow.

Occasionally, tuberculous abscesses may form from the degeneration of tuberculous lymph glands, and may closely simulate those found in underlying disease of the spine without, however, any evidence of vertebral bone destruction. In those joints in which the epiphyseal line is located outside of the joint capsule, such as at the wrist and ankle, the disease, starting in the metaphyseal region, may extend extra-articularly along the shaft; however, as a rule tuberculous disease involves the joints that are intra-articular, such as the hips, at an early stage. The tuberculous abscess is thought to contain defensive antibodies. Owing to the frequency with which this disease develops chronic sinuses after incision and drainage, surgery on the tuberculous abscess should usually be of a conservative type. Aspiration with a large-bore needle, the needle being inserted obliquely through healthy skin into the abscess, will permit its withdrawal without resulting sinus formation. Those abscesses in which spontaneous rupture might be anticipated should be drained in this manner, although occasionally deep pelvic abscesses need incision and drainage with injection of streptomycin and para-aminosalicylic acid (P.A.S.).

Multiple minute areas of the spine may be involved in the tuberculous process and these lesions are largely discovered only at autopsy and not by previous roentgenographic studies. *Multiple vertebral involvement* is not rare and should be constantly sought.

Amyloid degeneration may result from any long-continued suppuration and may, therefore, develop in patients with tuberculosis of the bones and joints. It is accompanied by emaciation, waxy pallor and enlargement of the abdomen due to involvement of the spleen and liver. It is usually fatal; death results from liver or cardiac failure. This complication is rarely seen today.

Treatment. Since tuberculosis is a systemic disease, the treatment should be twofold: (1) building up the general body resistance and (2) caring for the local lesion by both conservative and surgical measures. Streptomycin and related antibiotics have proven of great benefit

sions. In doubtful cases, *culture of the material* aspirated from the joint should be injected into a guinea pig, or *biopsy* of the affected tissue should be made. In very early cases the roentgenogram shows no evidence of bone destruction, but will very early disclose bone atrophy. If a positive diagnosis of joint tuberculosis is to be made, (1) the tubercle bacillus must be demonstrated in the microscopic examination of the excised tissue or joint fluid, or (2) tuberculous lesions must be produced in a guinea pig inoculated with the infectious material.

Prognosis. The prognosis of tuberculosis of the bones and joints depends in part upon the predisposition of the individual to the disease. Members of certain races, particularly Negroes and Indians, are especially susceptible. The prognosis also varies greatly depending upon the part affected and the age of the patient. In Pott's disease the proximity of the tuberculous disease to the spinal cord makes the patient susceptible to paralysis. It has been pointed out by Cleveland (1940) that patients with Pott's disease with metastatic spread to other organs have a mortality rate of about 70 per cent, even when the sputum examination reveals no tubercle bacilli.

Dissemination of bone tuberculous disease to important organs or other joints is always a possibility, and when the disease is also active in the lungs, it renders any prognosis especially poor.

Any chronic disease may leave the patient weakened and debilitated; therefore, patients with chronic diseases are much more susceptible to any intercurrent infection than are healthy individuals.

Complications. *Abscesses* are formed from the degenerated products of the local osseous tuberculosis. They are called "cold abscesses" because the usual evidences of local inflammation are not present. Abscesses may occasionally, because of their size and situation, render the patient's life in danger, for in disease of the spine they may involve the spinal cord or, by pressure, affect important neighboring organs. When the disease is in the low thoracic or lumbar vertebra, these abscesses may be identified by palpating them through the abdominal wall. They can be felt as sausage-like masses in the region of the pelvis, or can be noted by soft tissue roentgenogram. They often burrow for a considerable distance and at times can be found extending underneath Poupart's ligament, pointing in Petit's triangle, or appearing down on the thigh as fluctuant, nontender masses. In cervical disease, they may become particularly dangerous by causing pressure in the posterior portion of the throat, giving rise to respiratory embarrassment. As this accumulated tuberculous pus burrows, it infects the ad-

and which is accompanied by splinting and traction of the affected region during the acute stage. Wind and sunlight play an important part in all of these outdoor treatments. The skin is the first line of defense against invading organisms and heliotherapy seems to produce some special resistance to the *Mycobacterium tuberculosis* in the body. The wind is a cooling agent to the sun's rays and a tonic to the general constitution, stimulating the local circulation. In the sunlight the short wave lengths, of which the ultraviolet rays are the most important, are stopped in the outer layers of the skin, where they produce marked pigmentation. A patient receiving sunlight treatment must be carefully watched to avoid overexposure, which harms rather than aids the patient. This type of conservative care, as definitive treatment, was rarely employed in this country in the adult patient.

In children, where time is not such a vital economic factor, conservative medical treatment of joint tuberculosis always should be employed preparatory to surgical fusion, but very rarely is it possible to avoid surgery later.

By fusion or arthrodesis of a joint or joints the diseased areas are splinted internally and absolute immobilization is produced. Although certain joints lend themselves to an extra-articular fusion, others require an intra-articular method to assure the best opportunity for fusion. It should be emphasized also that certain joints lend themselves to fusion more easily than others. This is discussed under the individual regions involved.

Tuberculosis of the Long Bones

Tuberculosis of the long bones (Fig. 61), although rare in the United States, does occur and is often mistaken for a pyogenic type of osteomyelitis. Shaft tuberculosis, rarely rapidly progressive, is a chronic disease and is most frequently seen in the adult. It is often associated with active pulmonary disease or tuberculous disease in other portions of the body. The shafts of the tibia (29 per cent) and femur (27 per cent) are most often affected (Carrell and Childress, 1940). Incision and drainage with saucerization and closure of the wound is the surgical treatment of choice. Streptomycin is the medication of choice in these cases.

OSTEOMYELITIS

The majority of nontuberculous infections of the bones and joints are caused by staphylococcus, and streptococcus, but the colon bacillus,

in bone and joint tuberculosis; even in patients with a mixed infection, such as a draining sinus, streptomycin is very helpful. Deformities such as severe gibbus due to a massive collapse of the vertebral bodies are rarely seen today. The frequency of tuberculosis of the vertebrae is apparently on the wane and the cases of osseous tuberculosis that are seen are less severe, indicating either that the strain has become attenuated or that the disease today is recognized and proper treatment is instituted earlier. Deformity is usually not allowed to occur. Multiple draining sinuses are fortunately almost a thing of the past and paralysis, while not completely eliminated in clinical practice, is much less frequent. The spine is, however, the region most frequently involved in joint tuberculosis; the great majority of cases occur in childhood and the direct danger to life with vertebral disease is greater than with any other joint involvement. Slowly, the conception of improved hygienic surroundings, proper food, recumbency, traction and adequate drug therapy has been recognized by the medical profession. Today the treatment might be said to be: (1) general care, (2) proper and continued antibiotics in the delay period, and (3) surgical fusion.

Rollier (1927) in Switzerland and groups of surgeons in France, England and America demonstrated the value of heliotherapy when combined with rest. Bed rest alone, however, even with careful nursing and good food, will not prevent the development of deformities and the appearance of sinuses. Plaster of Paris casts, traction and braces must be employed to prevent and correct joint deformities. Traction alone, or in combination with these other agents, is of great value in the reduction of the concomitant muscle spasm and pain. Since occasionally some of these diseased joints ankylose naturally, they should always be maintained in good functional position. Today, it is recognized in the United States that surgical fusion will accomplish ankylosis much more quickly and economically than if one depends on natural fusion to follow conservative care.

The fresh-air homes, previously so popular in Europe for persons with bone and joint tuberculosis, emphasized the benefit of increasing general body resistance, the need for proper splinting, and the value of sunlight by gradual exposure until the whole body is tanned. Only in a small percentage of cases, however, has this alone produced permanent painless mobility in a tuberculous joint. One school stressed the benefit of high altitude in producing this effect, whereas another obtained similar results at sea level, the cardinal factor in both schools being a type of rest that is continuous, prolonged and uninterrupted,

and which is accompanied by splinting and traction of the affected region during the acute stage. Wind and sunlight play an important part in all of these outdoor treatments. The skin is the first line of defense against invading organisms and heliotherapy seems to produce some special resistance to the *Mycobacterium tuberculosis* in the body. The wind is a cooling agent to the sun's rays and a tonic to the general constitution, stimulating the local circulation. In the sunlight the short wave lengths, of which the ultraviolet rays are the most important, are stopped in the outer layers of the skin, where they produce marked pigmentation. A patient receiving sunlight treatment must be carefully watched to avoid overexposure, which harms rather than aids the patient. This type of conservative care, as definitive treatment, was rarely employed in this country in the adult patient.

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the pneumococcus, the gonococcus, Eberthella typhosa and other bacilli are all classed as *pyogenic organisms,* and any of these may at times be the etiologic factor. The most common of *fungi* giving rise to osseous lesions are the actinomyces and blastomycetes. In the United



FIGURE 61. Tuberculosis of the shaft of the femur.

States, by far the most commonly encountered bone and joint infections due to parasites are those attributed to Treponema pallidum.

Acute Osteomyelitis

In nontuberculous osteomyelitis, the two routes of infection are the *hematogenous* and the *exogenous,* the former being the more frequent. The portals of entry for infection may be a sore throat, a draining ear, an infected tooth, commonly a skin infection such as a furuncle or carbuncle, or any break in the skin Acute hematogenous osteomyelitis is the usual type, but the widespread use of antibiotics today has greatly lowered its incidence.

Acute osteomyelitis is most commonly seen in young children, but there is an acute osteomyelitis which occurs in adults (page 60)

which differs greatly from the disease of childhood in that the onset is slow and insidious and the development of the bone lesion more gradual.

Pathology. The long bones are formed of three different and important varieties of tissue: (1) cortical bone, (2) the marrow tissue and (3) the fibrous vascular membrane, the periosteum. The cortex of the bone is made up of cellular elements and matrix, whereas the marrow tissue is richly vascular, containing numerous thin-walled capillaries, veins and arteries, and is filled with two varieties of bone marrow, yellow and red. For many years the limiting membrane about the bone has been the subject of numerous controversies. The periosteum is a richly vascular fibrous membrane which in adult life is firmly adherent to the shaft of the bone. In childhood, except at the epiphyseal line, the periosteum strips from the cortex easily. At the epiphyseal ends of the bone, however, the periosteum dips into the epiphyseal line and is firmly adherent to the epiphyseal cartilage. Whether the epiphyseal plate is intra-articular or extra-articular to the joint capsule is of great practical importance in regard to the spread of the infection, as shown in Figure 62.

Circulation to a long bone is supplied in great part by the nutrient artery, which perforates the cortical shaft at about the middle of the bone and immediately divides, one branch going toward each extremity. This vessel and its tributaries supply the medulla and the endosteum, and anastomose freely with the cortical vessels through the Haversian canals. In addition to this main source of supply, the cortex is supplied by the periosteal vessels and the epiphyses are supplied from the capsular vessels. In brief then, the long bones are made up of two spongy ends; the shaft between is encased in a membrane (periosteum), and the hollow canal of the shaft is lined with endosteum and filled with marrow tissue. Included in the deep layer cells of the periosteum are the osteogenetic or regenerative type of cells. This type of cell is also found in the endosteum, but to a lesser degree. In the spongy ends (metaphyseal areas) of the bone are located the capillary loops where there is marked slowing of the blood stream and consequent pooling of blood.

Following any infection or minor injury, staphylococci normally living on the skin as saprophytes may become invasive (exogenous), or infected foci within the body (hematogenous) may discharge the offending organisms. The organisms, after circulating in the blood, reach the capillaries in the metaphyseal region of the long bones, and

then, owing to lowered local resistance, small inflammatory areas begin to develop. These small minute abscesses coalesce and thrombose, contributing to bone necrosis, so that the destructive phenomena of osteomyelitis, i e., septic necrosis and bone caries, ensue. Within 24

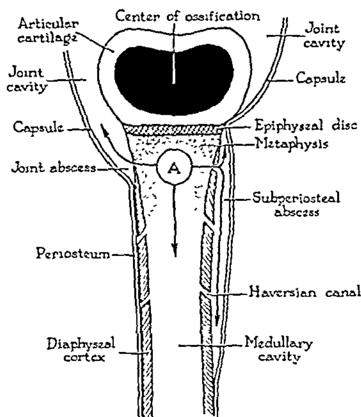


FIGURE 62 Methods of spread in osteomyelitis. It is important to recognize the intra-articular and extra-articular epiphyseal plate. (Modified from Starr, C. *Arch Surg.*, 4 567, 1922)

hours a definite change may be noted; the grayish necrotic parts become surrounded by an increased hyperemic zone. The infection ordinarily is carried by blood vessels to the medullary canal, then through the Haversian canals to the periosteum. The periosteum is easily raised from the cortex in children and the infection spreads more or less rapidly, depending upon the virulence of the infecting organism, and upon the resistance of the patient. After formation of the localized abscess, the neighboring joint, *if the metaphysis is extra-articular*, is usually protected from the spread of the infection by the firm attachment of the periosteum about the epiphyseal line. However, *if the metaphysis is intra-articular*, the infection often ruptures early into the joint space, giving rise to *pyarthrosis*. Direct extension

rarely occurs from metaphysis through the epiphyseal disc into the epiphysis, and then through the articular cartilage. Usually, several abscesses coalesce and then under pressure begin migrating subperiosteally by way of the Haversian canals. (See Figure 62 showing methods of spread.)

Clinical Picture in Children. The symptoms may be very mild, but usually local pain is a constant, early and prominent feature of acute osteomyelitis. There is localized tenderness over the underlying bone infection, with swelling of the soft parts. Usually, chills, fever and a high leukocyte count are a characteristic feature. There may be other signs of toxemia, such as headache, dry tongue, malaise, vomiting, a rapid pulse rate and a rather high temperature of 103 to 106°F. During this acute stage of the disease the infection is usually confined to the interior of the bone, and during the first 24 to 36 hours a very careful physical examination should always be performed and the advisability of an early blood culture kept in mind. Shortly, symptoms of localized pain and swelling increase and movement in the adjacent joint is restricted and painful. Soft tissue swelling is such that obliteration of the normal contour is noted. With the perforation of the periosteum by the abscess there will be a release of tension, resulting in diminution of pain and toxic symptoms. An overwhelming virulent infection or septicemia may, however, give rise to multiple foci and a rapidly progressive toxemia. As a rule, the infection becomes localized and the diagnosis can be made from the history and the signs and symptoms present. Laboratory data, however, must be available early.

Changes cannot be detected in the bone by roentgenograms in the early stage and the very pernicious habit of watchful waiting for roentgenographic bone changes before initiating antibiotic therapy is to be deplored and condemned. *In the average case, at least ten days will elapse before any roentgenographic evidence of bone destruction can be demonstrated.* When the change occurs, it appears as a rarefaction of cancellous bone near the epiphyseal line on the diaphyseal side. This early sign may be more apparent if roentgenograms of the opposite limb are taken as a control.

Although bacteremia is usually present at some time during the course of the disease, the infecting organisms are thrown into the circulation in "showers" and the culture will be positive only at these times. It is generally agreed that a positive culture may be difficult to demonstrate from the blood, even in a known case of acute osteomyelitis.

The age of the patient should be given careful consideration. Osteo-

myelitis in infants is different in many respects from the same disease found in older children. In osteomyelitis in infants under 2, the disease is much more frequently due to *Streptococcus hemolyticus;* if this is the case and the child survives the acute infection, complete cure and rapid recovery may be expected.

Acute osteomyelitis is usually seen in children from 2 to 15 years of age and is due to *Staphylococcus aureus* in about 90 per cent of the cases. If early treatment is not instituted in patients of this age group, extensive bone destruction occurs. In infancy this type of osteomyelitis is severe but of relatively brief duration. Usually, the infant rapidly improves or fails to survive. Sequestration, recurrences and residual lesions of the bones in infants are unusual.

Pyarthrosis should always be suspected when a joint demonstrates a resistant flexion deformity, severe muscle spasm and pain on passive movement. These complications can be expected more frequently with osteomyelitis at such sites as the upper and lower ends of the femur and the lower end of the humerus, for here the metaphyses are partly or wholly intra-articular and the joint can be infected by direct extension. Pathologic dislocation frequently accompanies pyarthrosis of the hip.

Prognosis in Children. This disease has a poor prognosis regarding restoration of normal structure and function unless early treatment is instituted. It is one of the great crippling diseases of infancy. The percentage of surviving healthy children with normal bone restoration has tremendously improved, however, with appropriate chemotherapy plus judicious conservative surgery. Generally patients with a streptococcus infection make a better recovery than those with a staphylococcus infection It has been estimated that within any age group 90 per cent of all deaths from acute hematogenous osteomyelitis occur in the first 2 weeks of the disease. A history of previous recurring skin infections is of serious import because it indicates insufficient resistance to the organism.

Treatment. The treatment of acute hematogenous osteomyelitis must be governed by the individual problems presented. A constant conflict exists between the general resistance of the patient and the virulence of the organism; therefore, an accurate determination of these two factors may require the utmost skill and diagnostic ability. The treatment should be considered under two headings: (1) immediate general supportive treatment, (2) early conservative operative treatment.

Immediate general supportive treatment. In those instances in which the patient is dehydrated and toxic or in a severe state of shock,

operative delay is almost always indicated until supportive measures can be instituted. Rest to the limb by use of a bivalved plaster cast or splint, gentleness in nursing care, frequent small blood transfusions (200 to 300 cc.), large infusions of saline or glucose (2000 to 4000 cc.), and heavy doses of the appropriate chemotherapeutic agent, with sedation on admission, usually are paramount. As a rule, the prognosis is better if operation is delayed until the defenses of the body have built up some local resistance to the disease.

The use of antibiotics has proved that the physician has an extremely valuable ally in both acute and chronic osteomyelitis. The employment of chemotherapy to which the infective organism is most sensitive is an urgent need. The usefulness of penicillin and other chemotheropeutic agents plus appropriate sedation cannot be minimized and, in spite of occasional danger, their early use in large doses is advisable. However, they should not be continued beyond a point where the natural defenses of the body appear able to take over, or when the causative organism develops a resistance to the drugs. The benefits of penicillin in acute hematogenous osteomyelitis are: (1) a marked tendency to arrest the local infection with absence of sequestra (if sequestra occur later, they can be removed by conservative surgery); (2) a lessening of the mortality rate; and (3) a lessening of the tendency to spread to other portions of the body, (i.e., a decrease in the metastatic nature of the infection). To produce these beneficial effects the drug must be given early and in large doses, 20,000 to 50,000 units every 3 hours for the first 3 weeks and then tapered off. No striking improvement will usually be noticed within the first few hours after starting the drug (Altemeier and Wadsworth, 1948).

The value of transfusion is obvious, and this form of therapy cannot be stressed too much. Generally, small transfusions of 200 to 300 cc. repeated every few days are preferable to large transfusions given at any one time.

Early conservative operative treatment. If and when surgery is indicated, it should be *conservative surgery.* The old practice of widely opening the bone along the length of the shaft and exposing the medullary canal a distance equivalent to the subperiosteal stripping (the so-called "gutter" operation) is never indicated. This method cannot be too strongly condemned; understanding the underlying pathologic process should make the futility and the danger of such treatment evident. It is of paramount importance that the general condition of the patient be determined first; this is the governing factor for considering an operation.

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If the patient's general condition seems satisfactory but the constitutional symptoms indicate a spreading infection from a local abscess formation, in spite of chemotherapy, immediate operation is sometimes advisable; but this should consist only of a simple incision and drainage. If there is a large fluctuating abscess, this needs draining; in certain instances, simple aspiration of the abscess with a large-bore needle and repeated local injection of the antibiotic is the method of choice. These patients should always be kept perfectly quiet by sedation and, if feasible, by some form of plaster splint to the region involved.

Types of operation. (1) Simple aspiration is very useful with localized abscess formation with or without the introduction of the chemotherapy solution into the aspirated area.

(2) Placing two or more drill holes in the direction of, but not into, the epiphyseal plate was first stressed by Starr (1922), and is occasionally helpful in obtaining adequate drainage at the metaphyseal area, or if the infection has spread into the shaft, a few drill holes can be made at this level.

Minimum surgery is desirable in the treatment of acute osteomyelitis.

Acute Osteomyelitis in Adults. The onset of acute osteomyelitis in adults is slower and more insidious and the development of the lesion gradual in all but exceptional cases. *Staphylococcus aureus* is the usual causative agent. Since the periosteum is more firmly adherent to the bone in adults than in children, development of subperiosteal abscesses is unlikely. The infection spreads chiefly through the central canal, which results in thickening of the shaft and some periosteal bone production; rarely does sequestration or metastatic involvement occur. *The roentgenographic picture is different from that noted in children,* and may even be confused with the picture of an endothelioma of bone (Zadek, 1938). Pain in acute osteomyelitis in the adult is not severe, and the rise in temperature is only moderate.

Large doses of penicillin should constitute the initial treatment. Occasionally saucerization of the bone and packing the wound open with petrolatum and immobilizing by plaster casing (Orr method, p 63) is the method of choice.

Chronic Osteomyelitis

Pathology. When the infection in the acute process extends along the periosteum and strips it up, sclerotic bone is laid down along the entire inner surface of the stripped-up periosteum. This shell of newly formed osseous tissue (*involucrum*) is characteristic of chronic osteo-

myelitis and may completely enclose the necrotic infected bone shaft. This covering of new bone is pierced by numerous sinuses (*cloacae*) which develop for the discharge of pus and bone debris. As time passes, these enclosed bony areas become completely ischemic owing to thrombosis of the cortical capillaries, so that the dead bone (*sequestrum*) lies completely loose in its shell of involucrum — *a dead body within its coffin*. Smaller spicules of bone may gradually find their way out through the sinuses to the skin surface.

The larger sequestra must be removed surgically. This operation is called a sequestrectomy. The method of spontaneous extrusion of encased sequestra is slow and may frequently not occur; thus time can be saved by their removal. As long as there are sequestra of sufficient size withing the involucrum, absorption by the processes of repair will not occur, and sinuses will persist.

In acute osteomyelitis, proper drainage, immobilization and drug therapy will often cause the constitutional symptoms to subside in a few weeks. However, the body resistance may not be sufficient to destroy all local evidence of bone infection, so that a high percentage of patients with acute osteomyelitis, even when properly treated, develop some degree of chronic osteomyelitis. The bone lesion, if extensive, not only has a debilitating effect upon the general health, but prolonged disuse of the infected region leads to muscle atrophy, adhesions in and about the joints, and formation of scar tissue and contractures. If the purulent drainage continues for a period of years, nephritis and amyloid disease may develop as complications.

In many cases of chronic osteomyelitis there may be long periods in which there are no local signs of activity. Then, owing to the stresses and strains of daily activity, some fresh insult to the local region by trauma, or lowered body resistance, a recrudescence of the acute symptoms will occur, i.e., heat, redness, tenderness, rise in temperature and all the signs and symptoms of an acute flare-up at the seat of the osteomyelitis. The way in which small nests of infection will quietly persist and be asymptomatic over a period of years is remarkable. Cases have been quiescent for thirty or forty years before becoming reactivated!

In long-standing cases with profuse drainage and extensive bone involvement, one occasionally will see the development of a malignant tumor, most commonly a squamous-cell carcinoma. *This possibility* must always be borne in mind and checked by biopsy.

Roentgenographic Findings. The roentgenographic picture in chronic

osteomyelitis demonstrates excessive bone proliferation, with areas of bone destruction, and often obliteration of the medullary cavity. The entire bone is thickened so that it is often irregular in shape, with small or large areas of absorption in which sequestra are often present. In the older cases enormously thickened sclerosed bone is found (Fig. 63).

Treatment. Surgical removal of the sequestrum is necessary, but at which phase in the course of the disease should this operation be performed? It is necessary to operate to drain the abscess or remove the

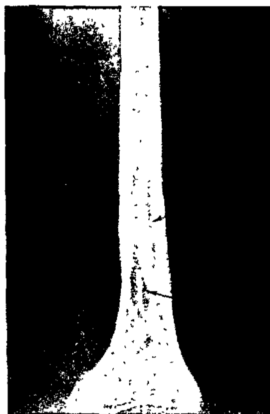


FIGURE 63. Chronic osteomyelitis with sequestra In many cases there is marked periosteal thickening (involucrum) surrounding the sequestra. Note loose sequestra in center of shaft.

sequestrum, but if possible one should always wait until it is certain that sequestration is complete. A few weeks preliminary to operation, hospitalization and intensive selective chemotherapy should be instituted. After this, *radical surgery is indicated.* This consists of. (1) thorough saucerization of the involucrum and removal of sequestra, (2) excision of scar tissue, and (3) curettage of the bony pockets and sinuses. *Care must be taken not to remove too much bone as this will render it liable to pathologic fracture.* Careful attention must be paid to smoothing off the floor and wall of the saucerized cavity so that

gross evidence of diseased tissue can at least be eradicated. This diseased tissue can be more readily identified if 1 cc. of methylene blue is *gently* injected with a syringe into the sinuses just before beginning the saucerization. After surgery, the adjacent muscle tissue is allowed to fill in the dead space as far as possible and the skin loosely closed. Many times, excision of the scarred tissue is so extensive that skin closure is not possible. Plastic operations, using split-thickness grafts or skin flaps and occupying months of treatment, must then be planned. Following surgery, the local use of chemotherapeutic agents or tight closure of the wound is rarely advisable, although continuance of systemic chemotherapy is helpful. A plaster of Paris dressing is applied, immobilizing the joint above and below the site of the disease.

Orr method. In chronic osteomyelitis the Orr method of treatment (Orr, 1929), or some modification of it, is frequently used. The Orr method consists of thoroughly removing the scarred tissue, saucerizing the diseased bone and packing the wound open with petrolatum gauze, after which a circular plaster cast is applied. The wound slowly heals by "secondary intention," the plaster cast being changed every 5 to 6 weeks, or when the odor or softening of the plaster makes such a change desirable.

Complications. *Pathologic fracture.* When the shaft of the bone is extensively involved in the osteomyelitic process, the bone structure becomes weakened and fracture may occur with minimal trauma, such as even turning over in bed. Again, fracture may occur when the sequestrectomy operation is too extensive.

Disturbance of growth. When the disease is confined to the diaphyseal portion of the bone, it produces a thickening of the shaft and occasionally an actual increase in longitudinal length. When the epiphyseal growth area is involved in the infection, growth disturbances are common. There may be a cessation of growth throughout the width of the plate or an unequal growth disturbance, giving rise to joint deformity.

Osteitis of Garré

Another form of osteomyelitis is the chronic, diffuse, sclerosing osteitis of Garré. This condition produces a dull ache which is usually worse at night. The region most often involved is the tibia. Roentgenograms show thickened cortical bone (Fig. 64). Before Jaffe's (1935) description of osteoid osteoma, many cases were miscalled chronic non-suppurative sclerosis osteitis. Brailsford (1942) still maintains that

osteoid osteoma is a chronic low grade inflammation. Osteitis of Garré may be confused with syphilitic periostitis, osteogenic sarcoma or Ewing's tumor.

Treatment. Thorough saucerization of the bone followed by complete closure is recommended.

Brodie's Abscess (Central Bone Abscess)

Brodie's abscess is a local, often sterile, chronic bone abscess, occurring most often in persons under 15 years of age, and slightly more frequently in boys than in girls (Fig. 65). It most often affects the lower end of the tibia, femur, humerus or radius, in the order named, and is usually limited to a single bone. The site involved is the medullary portion of the diaphysis. Dense sclerotic bone often surrounds the abscess, which usually produces no growth on culture.

Treatment. After thoroughly cleaning out the bone, it is saucerized, and the skin closed. The wound usually heals per primam.

OTHER JOINT INFECTIONS

As already mentioned under acute osteomyelitis, pathogenic organisms may penetrate the joint through the blood stream by direct extension from a nearby focus, or directly through a lacerated wound. (See individual joints.)

Gonorrheal Arthritis

Gonorrheal arthritis as an orthopaedic problem has greatly diminished since the advent of chemotherapy. The gram-negative, kidney-shaped gonococcus causes a high incidence of urethritis with occasionally a metastatic infection of articular tissue. However, less than 0.5 per cent of the arthritis seen today is due to gonorrheal urethritis.

The onset of joint symptoms, at first often polyarticular, usually occurs 10 to 20 days after the primary gonorrheal infection. It involves, in order of frequency, the knees, ankles and wrists. There is a three to one occurrence in males over females

Clinical Picture. The usual clinical picture of infection is seen in the adult male between 30 and 40 years of age. A few weeks following primary infection there is a polyarticular involvement, later localized to one joint which becomes swollen, red, tender and acutely painful to motion; this is accompanied by a general rise in temperature from 100° to 104° F. Smears and cultures of the aspirated joint fluid will reveal the gonococcus in about one-third of the cases, and the aspirated fluid



FIGURE 64. Sclerosing osteomyelitis of Garré.

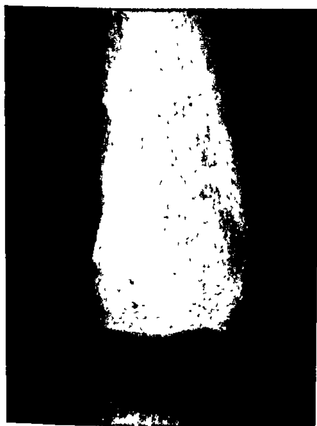


FIGURE 65. Brodie's abscess in a patient 18 years of age.

will reveal a high polymorphonuclear leukocyte cell count, and frequently a decreased sugar content. The gonococcus complement-fixation test is of doubtful value, although if a negative reaction becomes positive while the patient is under observation, one may assume it is due to a gonococcal infection.

Differential Diagnosis. Gonorrheal arthritis has been confused with *acute rheumatoid arthritis,* although in the latter the smaller joints are more likely to be involved. Also, in rheumatoid arthritis synovial-fluid cultures are negative for gonococcus, the disease is a gradually progressive one, and there is no dramatic response to penicillin within the first three days.

Reiter's syndrome, first described by Reiter in 1916, is a fever of remittent type, lasting about 17 days, accompanied by pains in the joints, urethritis, conjunctivitis and enlargement of the spleen. This type of arthritis may be indistinguishable on a clinical basis alone, but may be differentiated by the negative bacteriologic study and its lack of response to any chemotherapeutic agent.

Treatment. Almost all of the gonorrheal arthritic cases show a prompt response to penicillin. This drug therapy has revolutionized the problem of the joint changes which were formerly so common in gonorrhea. The great majority of cases are cured by a single course of penicillin given intramuscularly, 100,000 units in 24 hours. Streptomycin is equally, if not more effective than penicillin. Chemotherapy should be combined with joint immobilization in splints or in plaster of Paris casts, sedation and general care of the patient. Occasionally aspiration of the joint fluid will make the patient more comfortable. When intra-articular penicillin is used, it should be in addition to the intramuscular injection.

Brucellosis (Undulant Fever; Malta Fever)

Osseous changes associated with undulant fever (Malta fever) are unusual but appear to affect the spine more often than the other bones. This generalized infection is due to one of the species of *Brucella:* the *Br. melitensis* of goats, the *Br. abortus* of cattle or the *Br. suis* of hogs. It usually occurs between the ages of 10 and 30 years, and is the most common disease transmitted from animals to man in the United States. The fever may be intermittent or continuous, and, as the earlier symptoms are similar to those of typhoid and malaria fever, the differential diagnosis depends upon the agglutination test in the former and examination of the blood in the latter. Undulant fever

is primarily a disease contracted by man through the milk of infected cows. Brucella bone lesions are late sequelae, appearing from 8 to 12 weeks after the onset, and having a definite tendency to self-limitation. The preference of brucellosis for the lumbar spine is striking. It produces a narrowing of the joint space with some bone production, and runs a rather benign course. Johnson and Weed (1954) and others have reported brucella bursitis.

Treatment. Aureomycin, 3 Gm. given by mouth every 6 hours in divided doses, combined with dihydrostreptomycin, 2 Gm. given intramuscularly at 6 hour intervals, is very effective. The drug should be continued 2 to 3 weeks (Herrell and Barber, 1949). The local lesion in the spine usually responds to this treatment when combined with rest and immobilization in a plaster jacket. Very rarely is a surgical spine fusion necessary, as natural fusion usually occurs with immobilization.

Leprosy (Hansen's Disease) *

While leprosy is rarely seen in this country outside of the leprosaria it is of diagnostic importance because it has been mistaken for syphilis, tuberculosis and many dermatologic conditions. The disease is found especially in the humid climate of the tropics.

In 1874 Hansen discovered the disease to be cause by the *Mycobacterium leprae*, a small, beaded, acid-fast rod found in parallel groups. These are found in the nasal discharges, beaded nerves, skin surface, open lesions and nodules. Efforts to transmit the disease experimentally have failed, but in human beings the period from exposure to the appearance of lesions may be ten years or more. It is almost never contracted from contact with patients.

There are two principal forms: (1) the type characterized by skin tubercles which are bacteriologically positive and (2) the tuberculoid type which is bacteriologically negative. In this latter type there are anesthetic areas with loss of sensation to touch, pain and temperature; and trophic disturbances such as ulcers and bone and joint involvement also occur.

Roentgenographic Findings. Demineralization occurs in over half the cases. There is also bone destruction, especially in the joint areas where pressure is greatest. Loss of digits (spontaneous amputations) may occur (Fig. 66).

Treatment. During the early stages marked restriction of physical

* Frescoln (1949).

activity and isolation are recommended (Frescoln, 1949). The removal of pressure on the ulcerated areas stimulates healing. A 5 per cent solution of Promin as a nasal spray should be used as well as Promacetin, 2 to 3 Gm. daily, taken systemically; this has largely supplanted the



FIGURE 66. Phalangeal destruction in Hansen's disease.

use of chaulmoogra oil. It is thought that the sulfones act upon the fatty capsule of the bacillus and destroy it. There is no known immunization against leprosy.

FUNGI INFECTIONS

Actinomycosis

Actinomycosis is occasionally seen and is caused by the Actinomyces bovis (ray fungus), which is an anaerobe. The exact mode of infection of this disease is doubtful, but in man and other animals infection takes place via the mouth, although there is little evidence that the disease is contagious. In man the disease leads to great connective tissue proliferation with the formation of nodular masses, so-called "lumpy jaw."

In the osseous system, the spine is most frequently involved (about 2 per cent of the cases). The disease may simulate tuberculosis, syphilis, malignancy or other chronic bone lesions. Abscesses appear early, and yellow or semitranslucent granules about the size of a small pinhead may be seen in the purulent material These "sulfur granules" are quite characteristic of the disease. Roentgenograms of the actinomycotic spine will show extensive destruction of the body of the vertebra with very little new bone formation, thus resembling tuberculosis.

Treatment. Whenever possible, surgical removal of the diseased bone is indicated. The administration of potassium iodide over long periods of time is helpful. Vaccine treatment may be of some benefit and deep radiation therapy has been reported to be of value.

Blastomycosis

Blastomycosis is widely distributed about the United States, but is rarely observed in orthopaedic practice (Colonna and Gucker, 1944). Figure 67 illustrates the location and frequency of bone lesions. The

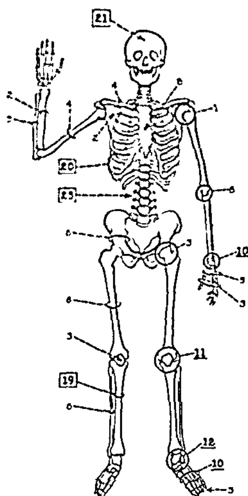


FIGURE 67. Location and frequency of the lesions in 67 recorded cases of skeletal blastomycosis.

first authentic description is said to have appeared in 1495 following the return of the men who sailed with Columbus to the West Indies.

The disease is characterized by multiple abscesses in the skin and by scar tissue. As far as is known it is not contagious. The skin lesions appear as elevated patches with dark red margins; the necrotic center

contains blastomycetes. When the spine is involved, the infection resembles Pott's disease. Over 50 per cent of the reported cases occur in persons between 20 and 40 years of age and men are affected in 90 per cent of the cases.

Treatment. Treatment consists of local excision when feasible, general constitutional therapy and administration of potassium iodide.

Sporotrichosis and Coccidioidal Granuloma

These are chronic infections rarely involving the osseous system, and the diagnosis rests upon isolating the *Sporotrichum* in the former and *Coccidioides immitis* in the latter infection.

PARASITIC INFECTIONS

An important parasite affecting bones and joints is the *Treponema pallidum,* the causative organism of syphilis. Ancient skeletal studies have revealed definite gross luetic lesions long before the parasite was recognized. Some lesions have been found of both congenital and acquired syphilis.

Congenital Syphilis

Syphilis is transmitted only through the mother, who may be infected by the father. The diagnosis of congenital syphilis of the bones and joints may be very difficult to make, and in most cases it is either finally confirmed or excluded by serologic studies and by roentgenographic examination of the long bones.

In the roentgenogram, bands of rarefaction are seen frequently in the diaphysis, especially in premature infants, but they cannot be regarded as specific for syphilis. After the infant has reached the age of 6 weeks, roentgenographic findings of congenital syphilis are more reliable. Periarthritis and bone destruction in the ends of the bones, along with a smooth, condensed, irregular epiphyseal line may be noted (Fig. 68). Roentgenoscopic study of the whole bony system should be made in such a case. Snuffles, eruptions, fissures at the corners of the mouth which may become ulcerated, and early loss of hair are all characteristic features in these poorly nourished, often premature infants. Often these infants appear to be paralyzed; muscle spasm and swelling of the joints with much pain and tenderness are also characteristic findings. Other stigmata, such as the saw-teeth of Hutchinson, occur



FIGURE 68. Subperiosteal reaction in congenital syphilis in an infant. Note the irregularity of ossification at metaphyseal areas with bone sclerosis.

later. This condition should be differentiated from rickets and scurvy.

Clutton's Joints. Chronic hydrops with a serous synovitis was described by Clutton in 1886 as a manifestation of congenital syphilis. It usually appears in children between the ages of 8 to 15 years. Most often it is bilateral and affects the knee joints. It may respond to antisyphilitic treatment.

Saber Shin. A localized syphilitic periostitis called "saber shin" affects primarily the tibia and consists of a thickening of the periosteum, always on the convex side of the bone. This disease responds very slowly to any form of antisyphilitic treatment. A saber shin appearance of the tibia may also be of rachitic origin. The roentgenographic picture of syphilis and that of rickets are so distinct, however, that a differentiation is not difficult. In syphilitic sabor shins the epiphysis is little involved while the diaphysis shows a production of new bone and thickening of the cortex, whereas the rachitic saber shin is a disturbance of epiphyseal growth with little change in the diaphysis except for its bowing.

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disturbances usually appear in the late stages. Charcot's joints occur most often in the weight-bearing joints, in the following order of frequency: the knee, hip, spine and ankle. They are believed to be the result of repeated trauma to the insensitive joint surfaces. Because of the trophic disturbance, the patient may suffer small fractures of the ends of the bones within the joint capsule and develop a wearing away of the cartilage and bone with, in some cases, proliferation of the



FIGURE 70. Charcot joint of knee.

articular cartilaginous and osseous tissue. The joints present a very striking appearance with relaxation of the capsular and ligamentous structures (Fig. 70). Flail-like joints develop, resulting in great instability. The painlessness of these luetic arthropathies is the most striking feature. Along with these late joint changes will be found important neurologic signs, such as absence of knee and ankle jerks, ataxia, Argyll Robertson pupil, loss of sphincter control, sexual impotence, Romberg's sign and certain sensory disturbances — all making the clinical picture a very striking one. The affection is usually monarticular, affecting the adult male most frequently.

Acquired Syphilis

Usually within three weeks following genital infection with *Treponema pallidum* a chancre appears, followed by swelling of the regional lymph nodes. Just before the appearance of the lesion, the patient experiences toxic symptoms of lassitude, fever and pains in the bones and joints. Pain may be severe, especially at the insertions of tendons. Syphilis involving the bones and joints may be of several



FIGURE 69 Luetic periostitis This is probably the most common radiographic finding in lues. This lacework pattern is characteristic and almost pathognomonic when the lesions are multiple.

types (Fig 69). Acquired syphilitic joint changes resemble those due to acute articular rheumatism Arthralgia in several of the joints may accompany the infection. Often one or more of the larger joints are affected. This is manifest by persistent aching that becomes worse at night. There may be no muscle spasm, swelling or local heat. Roentgenograms may show no evidence of disease, but the history and a positive serologic reaction will establish the diagnosis. Antisyphilitic therapy must be started promptly.

Charcot's Joint. In syphilis of the central nervous system, trophic

pathologic picture has been considered a basis for discussing chronic arthritis ever since the careful laboratory study on fresh specimens and the extensive autopsy report of Nichols and Richardson (1909). These workers demonstrated the underlying proliferative and degenerative processes in chronic arthritis.

Rheumatoid Arthritis

The terms *atrophic*, *rheumatoid*, *proliferative* and *ankylosing* are used synonymously in connection with this type of chronic arthritis. Under this large group are types that affect principally the spine: (1) the *rhizomelic spondylosis* type, called *Marie-Strümpell* or *"poker back"* arthritis of the spine (p. 82), rarely seen in females, and (2) *Still's disease* (p. 83), which originates in childhood, and was reported by Still in 1897.

General Considerations. Rheumatoid arthritis is most frequently seen in childhood and early adult life, 80 per cent of the patients being between the ages of 25 and 50, and is three times more common in females than in males. It is prevalent in the temperate zones and almost unknown in the tropics. It is recognized by early inflammatory changes in the synovial membranes and periarticular tissues with accompanying atrophy and rarefaction of the bones. It often begins with fever and pain in the joints and leads to severe disability and in its late stages to ankylosis of the involved joints.

The slender, overworked and overworried individual whose general health is below par and who has circulatory disturbances of the hands and feet frequently falls victim to this disease, particularly those persons under 40. There is certainly an hereditary as well as a personal predisposition. Usually this disease affects the metacarpophalangeal and wrist joints before the terminal phalangeal joints. The periarticular swelling of the soft tissues about the joints gives rise to spindle-shaped, fusiform joints, often containing an increased amount of synovial fluid.

Etiology. No causative organism has been definitely determined but predisposing causes are recognized, such as shock, fatigue, trauma, stress, infection, faulty metabolism, exposure and climate.

A great deal of research work has been done to determine the causative organism or organisms. Cecil *et al.* (1929) have recovered attenuated hemolytic streptococci from the blood and joint cultures of patients in 62.3 and 67.3 per cent respectively. However, their efforts have not been widely corroborated. This disease does not appear

Joint disability may appear very early as locomotor ataxia, even before syphilis is suspected. Trauma such as a fall apparently may be the initiating cause of joint pathology in the weight-bearing joints.

Syringomyelia, which also may cause trophic joint destruction, involves the upper extremity more frequently than the lower, whereas the reverse is true in Charcot's joint.

Diabetic arthropathy, most commonly seen in the foot, but also in other joints, may be confused with a Charcot joint. Cram (1955) has reported 27 cases, of which 62 per cent had diabetic retinopathy. All but 1 case had some reflex abnormality. Control of the diet and insulin therapy were followed by striking improvement.

Treatment. A long leg brace, or in milder cases a Jones knee cage, will give the patient some assistance in walking when the knee is involved. The neuropathic joint is usually a progressive one, although operations to fuse the affected joints have been recommended, particularly for the knee joint. A surgical fusion, however, is not easy to obtain if there is extensive destruction and should be undertaken only after serious consideration of the particular joint involved and its pathologic state. When and if knee fusion can be achieved, it is more desirable than wearing a permanent brace.

CHRONIC ARTHRITIS

It is important to have in mind certain broad characteristic features of chronic arthritis, with one's conception of the disease based primarily upon the pathologic picture.

Types. Chronic arthritic joints can be divided mainly into two types: (1) atrophic (proliferative) arthritis and (2) hypertrophic (degenerative) arthritis. It is also true that in many cases a mixed type of these pathologic processes is present, although either the degenerative or proliferative type will predominate. One can usually decide by the history, the clinical picture and roentgenograms, and always by the gross appearance of the joint, whether one is dealing primarily with the proliferative or rheumatoid type, or the degenerative or chondro-osseous hypertrophic type.

This simple classification is preferable to a more extensive and detailed consideration of arthritis based upon its etiology. The descriptive terms "proliferative or degenerative type of chronic arthritis" indicate the importance of the pathologic changes found, and have the added advantage of confirmatory evidence by roentgenograms. The



FIGURE 71. Rheumatoid arthritis in a young patient. Note fusiform enlargement at proximal interphalangeal joints of several fingers.

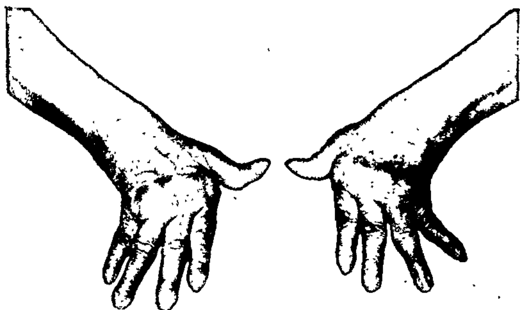


FIGURE 72. Severe grade of deformity in rheumatoid arthritis. Note deviation at metacarpophalangeal joints due to joint destruction.

to present a picture of a chronic, low grade infectious process. Research studies along bacteriologic, chemical and allergic lines have not revealed its etiology, though from its initial lesion there is reason to regard it as a type of deficiency disease, most likely of the collagen system.

Pathology. The characteristic features are the inflammatory joint and soft tissue changes affecting the interfibrillar substance of connective tissue. There is proliferation of the synovial cells and thickening of the synovial lining, round cell infiltration throughout the tissues, and marked change in the articular cartilage and underlying bone. A pannus formation of proliferating connective tissue is seen in the subchondral marrow spaces and about the periphery of the articular cartilage, encroaching further and further toward the center, strangling the cartilage cells as it advances. Erosion and destruction of the joint surfaces follow, finally resulting in bony ankylosis.

The soft tissue proliferation produces a swelling of the joints, and, as the muscles simultaneously undergo distinct wasting and atrophy, we find the skin over the affected joints becomes thin, tight and glossy.

When present, another pathologic finding characteristic of rheumatoid arthritis is the subcutaneous nodule, which occurs in about 10 per cent of the cases. These nodules are composed of an area of central necrosis with a surrounding zone of large mononuclear cells and an envelope of dense, fibrous connective tissue in which proliferation and degeneration predominate. These nodules are the same type as the granulomas of rheumatic fever, although larger.

Clinical Picture. The initial symptoms are frequently those of fatigue, lassitude, vasomotor disturbances, muscular stiffness and general debility. In 75 per cent of patients the onset appears gradually, occurring first in only one joint and then slowly involving others. Usually, the symptoms are stiffness and pain, followed by swelling and redness, and, as these affect one or more joints, they assume a progressive character with a tendency toward bony ankylosis and deformity. *Frequently, the costovertebral articulations and the sacroiliac joints ankylose early,* resulting in a definite limitation in the expansion of the chest wall and a lowered vital capacity; there is early roentgenographic evidence of sacroiliac fusion. In the hands, the fingers assume a characteristic stiffness with fusiform swelling of the proximal interphalangeal joints (Fig. 71). Later, all the fingers may be involved, giving rise to large knuckles and wrists (Fig. 72). These joints are involved early as are the tempo-

Every effort must be made to remove any probable foci of infection. Often this will not affect the course of the disease, but rather should be regarded as a sound hygienic measure. Although the condition in its early stages is fundamentally a medical problem, it must be remembered that joint irritation is one of the characteristic features; therefore, medical and orthopaedic care must go hand in hand. There is no condition in the realm of medicine which requires a more sane and balanced viewpoint than rheumatoid arthritis in evaluating the probable joint function which may be salvaged. This is not a disease in which the enthusiastic specialist should ride his hobby and glibly promise cures by various bizarre therapies. The physician treating the arthritic patient must have a broad, scientific training, an optimistic personality, infinite patience and unusual judgment in weighing and evaluating individual problems. Combined with this, he must have a willingness to study the patient thoroughly from every angle in order that both medical and orthopaedic problems may be carefully treated. The physician must constantly bear in mind the fact that this is a disease subject to spontaneous remissions and exacerbations; a good, well-balanced, nutritious diet is particularly needed for this type of patient, who is apt to be undernourished and underweight.

One of the most hopeful signs has been the report of the effects of an adrenal cortical hormone (cortisone). Cortisone has been employed in improving the clinical features and decreasing the sedimentation rate, at times with dramatic results. However, serious complications may follow indiscriminate use of this drug; therefore, the patient must be watched carefully. Tremendous work has been done by Hench, Kendall and others, reporting rapid amelioration of the patient's symptoms within 24 to 48 hours after the first injection. This improvement is characterized by a rapid decrease in subjective stiffness, joint tenderness and swelling. Coexistence of diabetes mellitus and rheumatoid arthritis should make the physician very careful in the use of cortisone and use of the drug should only be undertaken when the arthritis is progressive. The maintenance dose should be based on the patient's tolerance rather than on complete suppression of symptoms.

Hydrocortisone is another hormone which is now being used widely in intra-articular arthritis. Injecting 25 mg. of hydrocortisone after withdrawing a small amount of the increased joint fluid has at times been very helpful in both rheumatoid and hyperthropic arthritis. Benefit is usually temporary, but apparently in the majority of cases, the drug is harmless if injected at 10 day or 2 week intervals over a long

romandibular joints. In some cases muscular atrophy and weakness are the most striking features. Secondary anemia and moderate leukocytosis with an increased sedimentation rate are common findings.

As the disease progresses, flexion deformities occur in the elbows, knees, fingers and wrists, with subluxation at the affected joints (Fig. 73); typical subcutaneous nodules are also found. It is a progressive disease, although there may be alternating periods of quiescence

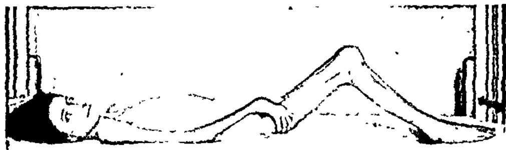


FIGURE 73. Rheumatoid arthritis. Typical multiple deformities have developed through inadequate or improper splinting. Note flexion contractures at wrist, hips and knees with equinus position of feet.

and activity. Finally the disease seems to "burn itself out," leaving joints which are deformed and often comparatively painless and which have varying degrees of stiffness.

Roentgenographic Findings. In early cases, the roentgenograms in rheumatoid arthritis may appear normal; soon soft tissue swelling, particularly in the posterior capsule region of the knee, appears, and also narrowing of the joint space. Atrophy of the cancellous bone due to diminished calcium content can be noticed, as well as small areas of spotty bone destruction indicative of bone erosion. As the process continues, destruction of the joint cartilage progresses, resulting in bony ankylosis. Subluxation at the joints is a frequent complication in the later stages due to both muscular action and joint destruction.

Treatment. Local treatment of rheumatoid arthritis must prevent or correct joint contractures; general constitutional treatment also must be given in this chronic, progressive syndrome. In the active stage, hospitalization is recommended, at least until the patient is afebrile; hospitalization simplifies the care of the patient by providing complete rest and good medical, orthopaedic and nursing care. Various forms of physical therapy have a place in the treatment, and proper protection of the affected joints should be attained by orthopaedic appliances.

the limit of painlessness. Emphasis is placed on the dangers of overtiring the patients or irritating the joints, which may aggravate rather than relieve the pain and muscle spasm. Sometimes, a change of climate for these patients is of extreme benefit. A dry, warm climate combined with sun bathing and rest in proper amounts are of definite benefit. The carbon arc lamp as a substitute for sunlight is of some value in improving the general tone of the body and lessening the infectious process of the joints. All of these measures should be available. It is most desirable that the internist and orthopaedic surgeon closely cooperate in the treatment of these patients.

Prevention and Correction of Deformities. The application of proper plaster or brace support in order to prevent and correct joint deformities requires familiarity with the use of plaster and appliances (Fig. 74). Deformities should be treated by conservative treatment, or even

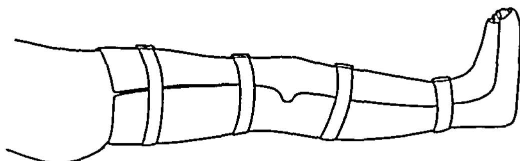


FIGURE 74. Bivalved plaster splint held in position with straps of webbing. This permits removal for baking and massage, but provides protection and support at other times.

by surgical measures in selected cases, in order to keep the joints in the best attitude for future weight bearing. Gentle manipulation of a joint under an anesthetic may permit a greatly increased range of motion. (See individual joint care.)

Occasionally, a synovectomy operation, removing the synovial membrane as completely as possible, particularly in the monarticular type of arthritis noted in the knee joint, may transform a boggy, swollen, tender, painful joint with very little motion into one with a satisfactory range of movement. This is a most useful operation in selected cases.

Joint reconstruction operations, surgical fusions, arthroplasties, capsulotomies, tenotomies, all are operations of value in the rehabilitation program for the chronic arthritic and are discussed in some detail by Campbell (1956).

period of time. It is to be remembered that cortisone and its derivatives, as well as the gold salts, will permit the patient to remain in remission often for months or even years, but they will not cure the arthritis and the physician should be sparing in their use. It is essential that the internist and the orthopaedic surgeon work closely together in the care of rheumatoid arthritis.

The salicylates are most helpful for the alleviation of pain. Colloidal sulfur has some advocates, but it cannot be recommended. Prior to adrenal and pituitary hormone therapy, gold salts, though somewhat dangerous because of the possibility of gold intoxication or complicating skin rash, offered the most promising results when used under carefully controlled conditions. Gold salts are still useful, and interchanging them with the pituitary adrenocorticotrophic hormones is often effective.

Rest. Regulated rest is one of the most important measures, and this should include rest to the body as a whole as well as to the part or parts involved. However, this does not always mean fixed immobilization, but rather a regulated regimen of restricted physical activity until the return of joint function and the physical rehabilitation of the patient as a whole is complete.

Diet. In addition to seeking and eradicating foci of infection, anemia and undernutrition must be corrected. A well-balanced diet containing fresh vegetables and fruits with a restriction of carbohydrates and proteins must be outlined for the patient. Energy in the body can be supplied by the fats and a high vitamin diet. Sometimes intestinal stasis appears to play a role in this disease, and those patients with intestinal intoxication will be benefited by high colonic irrigations.

Physical therapy. Physical therapy combined with the proper supportive appliances for the prevention and correction of joint deformities is useful. This therapy also increases the circulation to the impaired joints and permits rest to the part as needed. Heat is the most valuable modality, employed both generally by induced fever therapy and locally by dry heat to the individual joint. Dry heat is recommended in preference to the wet, moist heat in baths, for in addition to stimulating the circulation, dry heat produces copious perspiration. Contrast baths or alternating hot and cold douches to the affected region stimulate the sympathetic system and improve local circulation to the joints. Massage must be done gently, if at all, as many of these joints are sensitive and swollen, but, at times, it seems very beneficial if skillfully applied. Active and passive exercises of the joints must be done within

rise to an awkward, shuffling gait and a bowed and deformed spine. If the cervical spine also is involved, the head is held rigidly and, if bowed forward, the patient is able only to look downward. Many of these patients may later become bedridden.

Treatment. Early prevention of ankylosis in poor position is of prime consideration, for a stiff deformed spine may make walking very difficult, and the bowed position of the spine makes it impossible for the patient to straighten the neck and look forward. Therefore, corrective treatment toward preventing a fixed deformity must be started early. An improved posture should be sought by having the patient sleep on a firm, flat mattress; even bed rest with traction straps to the occiput and pelvis tends to stretch early ligamentous contractures and straighten the spine. Many of these patients suffer a great deal of back pain. Roentgen therapy, if combined with mechanical correction, lessens such pain considerably.

Still's Disease

A form of rheumatoid arthritis which affects children was reported by Still in 1897. In addition to the joint changes of rheumatoid arthritis, there is hyperplasia of the lymph nodes, frequent enlargement of the liver and spleen, and at times amyloid degeneration. The disease presents swollen, painful, tender joints, and severe flexion contractures quickly develop. General constitutional symptoms of active polyarticular rheumatism are present. The activity in time will become quiescent, but the same general treatment regarding prevention and correction of deformities should be followed as in other types of rheumatoid arthritis. Occasionally these patients recover spontaneously, but as a rule the disease is progressive, leaving the patient deformed and with marked limitation of motion in the previously affected joints.

Hypertrophic Arthritis (Degenerative Arthritis; Osteoarthritis)

In contradistinction to the atrophic type, this is largely an affection of individuals past middle age, characterized by degenerative and hypertrophic changes in the articular cartilages of the joints, with at times thickening of the synovial membrane. Pathologically, it presents a degenerative process in both its general and local form. The general form is polyarticular, affecting both the large and small joints, whereas the local form in monarticular and may be secondary to trauma. It is a noninfectious process. It occurs most frequently in the hips, knees, hands and lumbar spine, but any joint may be affected. It is charac-

Spinal Form of Rheumatoid Arthritis (Poker Back).

Spondylitis rhizomelica, Marie-Strümpell spondylitis (Fig. 75) or "poker back" type of spinal arthritis was described by Strümpell in

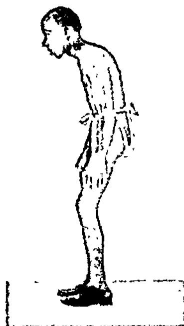


FIGURE 75 Typical attitude of patient with Marie-Strümpell spondylitis.

1897 and Marie in 1898. Although it often develops without a known etiologic factor, it is thought to be frequently associated with some other infection.

Pathology. It is characterized by more or less complete ankylosis of the spine along with a tendency to calcium deposition in, and eventual ossification of, first, the anterior longitudinal ligament, and later, all the intervertebral ligaments of the spine, including the posterior articulations. It is rarely seen in females and occurs most frequently between the ages of 20 and 40. This primary ossification of the anterior longitudinal ligament, and later of all the intervertebral ligaments, gives the appearance in roentgenograms of molten lava having been poured into these areas where it then hardened. Because of the shape of this type of spine in the anteroposterior view, it has been called the "bamboo spine." The vertebral bodies show some atrophy but retain their shape.

Clinical Picture. This is a spondylitis with stiffness, pain and diminished chest expansion. Progressive ankylosis of the spine follows, giving

or normal menopause. Pain and stiffness are frequently produced in the knees, fingers and spine. Women between 45 and 55 may have degenerative changes characteristic of the hypertrophic arthritis. This symptomatology may occasionally be seen in young women, and yet there may or may not be roentgenographic signs of osteoarthritis.

Clinical Picture. Hypertrophic arthritis is often more monarticular than polyarticular, and stiffness occurs early. The patient is usually within the age group which shows other evidences of senile change, and bony enlargement of the distal interphalangeal joints (Heberden's nodes) are frequently found (Fig. 76). Pain, with joint limitation and

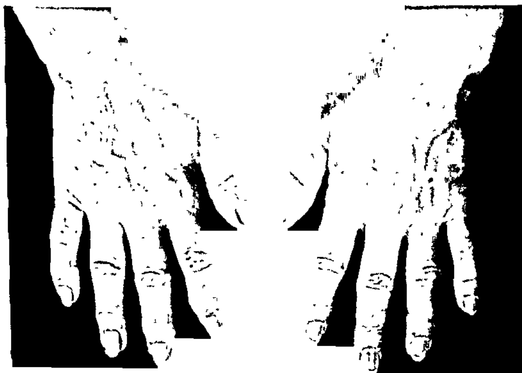


FIGURE 76. Heberden's nodes at the distal interphalangeal joints. (Courtesy of Dr. Joseph Hollander; *photograph from Comroe, B. I. Arthritis.* Philadelphia, Lea & Febiger, 1949.)

considerable disability, follows in many of the cases. The affected joint is usually pulled into a deformed attitude by the stronger groups of muscles about the joint. Therefore, flexion and adduction with outward rotation develop at the hip in malum coxae senilis.

Swelling of the soft tissues about the exit of the spinal nerves as well as the presence of osteophytes around the spinal nerves produces a narrowing of the vertebral foramina, which may cause severe limitation of motion in the lumbar spine, and referred pain down one or

terized by roentgenographic "lipping," and by the presence of bone exostoses in and about the articular margins of the joints.

Pathology. In the atrophic type, one of the earliest joint changes may occur in the synovial membrane, whereas in the hypertrophic type the synovial membrane will often appear normal in the early stages. If involved, it may be somewhat thickened by repeated trauma. In the later stages, osteocartilaginous loose bodies may develop within the joint. No pannus formation is found, which is in contradistinction to rheumatoid arthritis. Synovial fluid is rarely found in excess and microscopically it reveals no characteristic picture.

The most significant change is in the articular cartilage and bone. The articular cartilage loses its bright glistening color and becomes somewhat yellowish, with fibrillation of its fibers. The areas of cartilage "wearing away" are found at the points of greatest stress and strain, which are towards the center of the articular cartilage rather than at the periphery. Chondro-osseous spicules (exostoses) form quite early about the articular cartilaginous edges, giving the gross appearance of a grinding away process with peripheral accumulation of degenerative tissue. Distinct irregularities are produced in the opposing articular surfaces. The normally smooth, shiny, glistening cartilage is worn away until the underlying bone becomes highly polished or eburnated. These changes manifest themselves first in the central or more poorly nourished portions of the articular cartilage, with the degree of lipping or spur formation varying in the different osteoarthritic joints. True ankylosis of the joints does not occur in degenerative arthritis. If the patient is accustomed to hard labor, the spurs develop earlier and are larger. These osteophytes occasionally may become partially detached and form one or more loose bodies within the joint. If completely detached, they may wander about in the joint causing mechanical locking when they become caught between the articular surfaces.

The rare *von Bechterew* type is a degenerative osteoarthritis involving only the spine. *Malum coxae senilis* is also an osteoarthritis affecting the hip and possesses a similar underlying pathology (Chapter 9).

Traumatic osteoarthritis, which follows local injury or infection, will produce exostoses about the articular margins of the joint. As a rule, the joints do not present an exactly similar pathologic picture in their cartilaginous degeneration, although by roentgenogram, they may locally appear to resemble a degenerative osteoarthritis.

Menopausal arthritis may develop in patients having an artificial

here, as in the atrophic type, the salicylates are of some value in combating pain.

This is primarily a degenerative process so that many of the disabilities are mechanical problems. In the early stages, local heat and proper support by a posterior plaster shell or brace are useful. Both prevention and correction of deformity should be the aim of the physician. At times, this may be accomplished by manipulation of the joint, traction to the affected part and rest from the weight-bearing position.

Correction of the *soft tissue contractures* can be accomplished by: (1) muscle stripping, (2) stretching of the joint or (3) tenotomy. When the bone deformity is marked, the following operative procedures are available: (1) capsulotomy, (2) acetabuloplasty, (3) synovectomy, (4) removal of the osteophytic growths about the joint to improve the range of restricted motion (débridement), (5) removal of the loose bodies that may appear in the joint, (6) arthroplasties, (7) reconstruction operations, and (8) occasionally even fusion operations. All these operations must be in the armamentarium of the orthopaedic surgeon to be applied to the individual problems presented.

Gout (Podagra)

Gout may be both an acute and a chronic articular manifestation producing pain and deformity. It is a metabolic disease of unknown origin with a marked hereditary predisposition. Ninety per cent of all cases occur in men, with the greatest incidence beyond the age of 30, and is practically unknown in the Negro. The condition is especially prevalent in those stocky individuals in the fifth, sixth and seventh decade of life with an excessive intake of purine substances or alcohol, both of which may provoke an acute attack. It may assume many of the characteristic features of osteoarthritis or rheumatoid arthritis, and it especially affects the big toe joints. Sometimes tophi can be detected in the knuckles of the hand or the helix of the ear, and these are pathognomonic of gout whenever sodium urate crystals can be demonstrated.

Pathology. Crystalline sodium biurate permeates the articular cartilage, especially near its surface, with degeneration of the central portion of the articular cartilage matrix and sometimes the neighboring ligaments, tendons and synovial membrane. It may sometimes penetrate the skin.

Clinical Picture. The acute attack may occur suddenly and last for 3 to 10 days. It sometimes develops at night within a few hours, ac-

both of the extremities. Referred intercostal pain may occur in severe osteoarthritis. This is a nonankylosing type of arthritis so that the joint surfaces have no tendency to bony union. However, when large, the osteophytic masses may at times fuse together, giving an extra-articular ankylosis. The weight-bearing extremities and the spine are much more frequently affected than the upper extremities.

Roentgenographic Findings. The roentgen examination will rarely disclose soft tissue thickening, but it will show extensive changes in the articular surfaces, narrowing of the joint space and osteoarthritic changes about the margins of the joint (Fig. 77). The bones them-



FIGURE 77. Marked hypertrophic arthritis of the lumbar spine with spur formation.

selves become irregular in outline, producing an incongruity of their articular surfaces.

Treatment. The same general treatment used in the atrophic or rheumatoid arthritis must be employed in the hypertrophic or degenerative type of arthritis. The principles of rest, general constitutional care, diet and removal of predisposing causes are all of value. No specific medical treatment is known for hypertrophic arthritis, although

Treatment. Reduction in weight of the usually obese individual is of importance.

In *acute gouty arthritis,* cathartics should be given and 5 to 10 doses of colchicine, 1/120 grain every hour, taken until pain is relieved or nausea, vomiting or diarrhea intervene. Cinchophen, 7½ grains 3 or 4 times daily, can be used and either of these is preferable to the wine or tincture of colchicum. When gastrointestinal symptoms develop, 5 cc. of tincture of camphorated opium should be given. Many prefer acetylsalicylic acid, 60 to 90 grains daily, to the use of cinchophen. Rest should be given the affected part and hot or cold compresses applied (Freyberg, 1948). The elimination of the glandular type of meats is recommended, as well as a liberal intake of fluids. A low purine diet should be followed. Phenylbutazine (Butazolidin), given orally in 100 to 200 mg. tablets, is helpful when used for short periods under the supervision of the physician.

Osteochondromatosis

This condition has been regarded as a benign type of tumor arising from the synovial membrane of the various joints, but especially the knee, elbow, hip and ankle. It is characterized by loose body formation and many times these loose bodies give rise to mechanical obstruction to joint movement. Surgical removal is then indicated.

Osteochondritis Dissecans

This condition is characterized by a partial or complete separation of an osteochondral mass from the articular surface of one of the opposing bones in a joint. It is a noninfectious process; presumably it may be initiated by a thrombosis of one of the end arteries or by repeated trauma. The process is most commonly seen in the knee and less frequently in the hip, elbow and ankle joints. It is more fully discussed under these regions. When the osteocartilaginous mass becomes free in the joint its removal is indicated.

EPIPHYSEAL DISTURBANCES

The epiphyses, their appearance and fusion are discussed in some detail in the regional chapters, to which the reader is referred. Although the etiologic factors in certain epiphyseal affections cannot always be determined, there is little evidence to support the belief that these

companied by severe pain in the involved joint. The joint is swollen and tender, the metatarsophalangeal joint of the big toe being involved in about 50 per cent of patients. The skin is a deep red color and the veins are distended. If the acute attack is not treated specifically, symptoms may last for several days or several weeks.

In chronic gouty arthritis, the joints may become swollen and misshapen; and tophi are found in approximately 50 per cent of the cases. Recurring attacks of acute joint pain with completely asymptomatic intervals are very characteristic of gout.

Laboratory. The level of *serum uric acid* is normally from 2 to 6 mg. per 100 cc. and is more reliable than uric acid determinations on whole blood. Frequently, but not always, the excretion of uric acid increases during an acute attack of gout although it may diminish between attacks, but there is almost invariably a hyperuricemia present in patients with gout.

Roentgenographic Findings. In the earlier stages of the disease, there are normal findings in the roentgenograms. In the fingers and toes the small "punched-out" bone lesions are situated at the articular edges of the bone, being characteristically found in the late stage, whereas cystic lesions of chronic nongouty arthritis are usually seen in a more central position in the bone (Fig. 78).

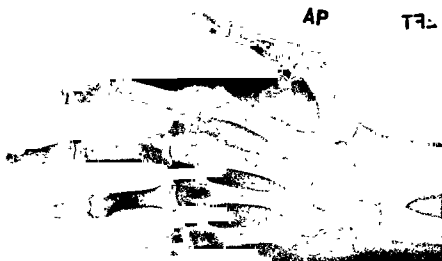


FIGURE 78. Gout Note characteristic "punched-out" areas in phalanges.

Prognosis. If gout occurs in early life, the prognosis is poor; it is considerably better if the onset occurs when the patient is over 50.

insistence on protection of the joint from weight bearing lessen distortion of the involved epiphysis. When deformed, healed articular surfaces result; these are often the seat of a traumatic arthritis in middle or later life. The reason for this is that the irregular joint surfaces produce a mechanical incongruity, so that even these healed joints will in time produce a traumatic osteoarthritis.

BONE CHANGES OF ENDOCRINE ORIGIN

The diseases of bone which are clearly dependent upon a hyperfunction or a hypofunction of the so-called ductless glands of the body are comparatively few in number, but continued careful research along these lines will doubtless make it possible to determine the factors producing certain pathologic changes in bone not understood at present. The ductless glands of the body include those glandular tissues whose secretions are eliminated through the blood and lymph instead of being carried off by ducts; the term "ductless glands" seems to have first been employed by Claude Bernard. Later, interest in the subject was greatly stimulated by Brown-Sequard and recently by Fuller Albright (Albright and Reifenstein, 1948) and many others. However, certain glands such as the pancreas give off internal secretions, even though provided with ducts.

The ductless glands play a powerful role in the general nutrition of the body, and their dysfunction produces striking effects. Malfunction of the thyroid, parathyroid, pituitary and adrenal glands particularly give rise to bone changes of interest to the orthopaedic surgeon. However, it must be understood that the bone changes which may be evident because of endocrine disturbances are but a part of the total picture. A complicated interrelationship among the different glands occurs. The pituitary gland not only controls growth directly by its somatotrophic hormone, but it also influences many other glands by specific trophic hormones. Other glands also secrete hormones which exert stimulating or inhibitory effects upon the pituitary gland and upon each other.

Thyroid Gland

The thyroid gland is formed by two elongated lobes lying at the base of the neck on each side of the trachea. They are normally about 5 to 6 cm. long. The gland serves as a storehouse of iodine, and elaborates an

conditions are infectious in origin. The most accepted theory is that the epiphysis, and often its adjacent metaphyseal area, undergoes an aseptic softening process, with its distortion and characteristic roentgenographic appearance due to an underlying circulatory interference induced by direct or indirect trauma.

In the spine, an epiphyseal affection is known as Scheuermann's disease; in the hip as Perthes' disease; in the tarsal scaphoid as Köhler's disease; in the head of the second metatarsal bone as Freiberg's disease; in the carpal semilunar bone as Kienböck's disease; and in the tibial epiphysis as Osgood-Schlatter's disease. There are other areas of involvement which are also discussed in the individual regional chapters. Pathologically, in all these affections there is an avascular necrosis which in the weight-bearing joints results in deformity with marked roentgenographic changes of the osseous center and its surrounding shell of cartilage. These pathologic changes occur only in the younger age period of life. The amount of disturbance necessary to cause pain and muscle spasm in a joint must be small, for in patients with avascular epiphyseal necrosis, associated with pain and muscle spasm, no accompanying slipping or displacement of the affected epiphyses is noted. Epiphysitis occurs most frequently in the early growth period of childhood and some observers believe the primary cause initiating the process is one of metabolic disturbance. The clinical symptoms are local tenderness and moderate swelling of the soft tissues, with muscle spasm. In Perthes' disease the symptoms are at times so severe that the condition clinically resembles tuberculosis of the hip and was confused with tuberculosis before the widespread use of the roentgenogram.

Treatment. The general treatment of these epiphyseal disturbances consists of rest from weight bearing or restriction of any movement that will produce pressure upon the bone or portion of bone involved in the avascular necrosis. When the joint is thus protected, a gradual absorption of the avascular necrotic area with resubstitution or revascularization by normal bone trabeculae usually occurs. This is a slow process, but all attempts to improve the local circulation and hasten repair by other means have to date had only moderate success. The effort to associate these conditions with hormonal disturbances has not been successful.

Prognosis. After distortion of the epiphysis has occurred through the forces of pressure, a certain amount of permanent limitation of motion and structural change remain Therefore, early recognition and early

followed by recalcification and relief of symptoms referable to the skeletal system. In cases of so-called "senile osteoporosis" investigation of the thyroid function should be mandatory. Spontaneous fractures occasionally occur in the decalcified bone areas; compression fracture of the spine may be the first evidence of an underlying thyroid hyperactivity.

Parathyroid Glands

These glands usually are four in number, and are located on the upper and lower poles of the lobes of the thyroid gland. Aberrant parathyroid glands have been frequently found. These ductless glands are normally 6 to 7 mm. in size, salmon or yellow in color, and are composed of a composite mass of glandular cells. Their abnormal activity may give rise to a tremendous disturbance of the calcium and phosphorus metabolism with subsequent bone changes of striking degree. If all the parathyroid glands are surgically removed, death will result unless the patient is sustained by parathyroid hormones.

Hyperparathyroidism. *Von Recklinghausen's disease* (*osteitis fibrosa cystica; osteitis fibrosa generalisata*) was described by von Recklinghausen (1891) when he reported two cases of softening of the bones with generalized decalcification of all of the bones. Most cases occur in adult life.

As the typical case is believed to be always due to hyperfunction of a parathyroid gland, it would seem that the name hyperparathyroidism is more appropriate. This hyperactivity may be due to single or multiple adenoma or very rarely to carcinoma of one of the parathyroid glands; in cases developing an adenoma, only a small percentage present multiple fibrosa cystica of the bones. Decalcification of the skeleton is more usual. Statistically kidney disease is more common in hyperparathyroidism than bone involvement, though one may have hyperfunction of the parathyroid glands without either bone or kidney disease.

Hyperactivity may be caused by an aberrant parathyroid gland which may be difficult or impossible to locate. They have been reported in various portions of the neck region, even behind the sternum.

The work of Mandl (1926) proved that the osteitis fibrosa cystica of von Recklinghausen was due to a parathyroid adenoma with hyperplasia and not the reverse, as had previously been held. Mandl was the first to remove the parathyroid tumor surgically, and in his patient this was followed by an immediate remarkable improvement.

Clinical picture. The decreased density of the bones and the presence

iodine-containing substance which has a controlling influence on growth and body metabolism.

Hypothyroidism. *Myxedema.* Occasionally in the adult one may see the effects of atrophy of the gland, or of its complete removal. The resulting decrease or absence of thyroid hormone produces myxedema. This condition is rarely of orthopaedic interest, is usually gradual in onset, and occurs most often between the ages of 30 and 60. The mental and bodily activities gradually slow down, the weight increases and the face undergoes a curious change. The features become masklike, the eyelids puffy, and the hair and eyelashes fall out, or the hair is scanty, coarse and bristly. With a nonpitting type of edema the skin is particularly dry and scaly. The basal metabolism is low and should be obtained to determine the presence and progress of the condition. Oral administration of desiccated thyroid is indicated.

Cretinism. Cretinism may be due to congenital absence or hypofunction of the thyroid gland. In infancy or childhood, deficiency of the thyroid secretion may give rise to juvenile myxedema. Cretinism usually manifests itself from the second to the sixth month of life.

This entity may give a general clinical picture somewhat resembling chondrodystrophia, but in contrast the patients present an obvious mental impairment due to thyroid deficiency. The typical picture of the *cretinoid dwarf* shows a child with a large protruding tongue, thick lips, flattened nose and dry skin. The belly is prominent and umbilical hernias are common. The roentgenogram shows an insufficient bone development for the age of the child. In juvenile myxedema the patients have a waddling gait and are usually incapable of being taught to read or write.

Rarely is there any necessity for orthopaedic treatment. The administration of thyroid extract is indicated, and the younger the child, the greater the improvement under therapy. In the cretin, treatment must be continued throughout life, but the prognosis for mental and physical improvement is poor.

The prognosis, following thyroid therapy, is better in myxedema than in cretinism.

Hyperthyroidism. *Graves' disease (exophthalmic goiter).* In this condition the thyroid gland is hyperactive. In these patients a certain degree of decalcification of the spine is often noted and they may present symptoms of back pain showing evidence of marked vertebral decalcification. Osteoporosis may be present throughout the body. Cases have been recorded of Graves' disease in which thyroidectomy has been

terminal phalanges. The "ground glass" appearance of the skull and the cortical cystlike areas are characteristic features (Fig. 80).



FIGURE 79. Parathyroid tumor with von Recklinghausen's disease of the bones. Note (*left*) the punched-out areas with bone absorption and extreme decalcification, making pathologic fracture easy. *Right*, same case ten months after removal of parathyroid adenoma. Note healed pathologic fracture with striking changes in bone texture.

Treatment. If the adenoma happens to involve one of the normally placed parathyroid glands, surgical removal is indicated; the subsequent degree of bone healing may be very startling. Often aberrant parathyroid glands, which are inaccessibly placed for surgical removal, may be involved and in this case radiation should be tried, even though the results have not been too encouraging.

Normal parathyroid glands are practically insensitive to radiation. It is doubtful that any medication such as the administration of calcium, phosphorus or vitamin D has any beneficial effect upon the adenomatous

of one or more definite cysts are characteristic changes; however, all degrees of skeletal decalcification with all kinds of bone deformity occur. Pain and tenderness of the affected bones are usual. Polyruria, polydipsia and renal stones are common complications. We find a thinning of the skeletal system, and also multiple bone cysts, so that spontaneous fracture frequently results. One of the very first signs (Albright) of hyperparathyroidism is manifested by decalcification and disappearance of the lamina dura of the teeth (see Fig. 80). Marked muscle weakness and lack of appetite accompany the skeletal change. Notwithstanding the characteristic signs and symptoms of the condition, the diagnosis of generalized von Recklinghausen's disease is usually not made until the late stage and often the bone pain or aching is mistaken for rheumatism.

Metabolic studies. The serum calcium is elevated to 10 to 20 mg. per 100 cc. (normal, 9 to 11), and the phosphorus content of the blood is low, 1 to 2 mg. per 100 cc. (normal, 2.5 to 3.5). The alkaline phosphatase is practically always increased, from 12 to 20 Bodansky units (normal adults, 1.5 to 5), for in this disease, and in several others, such as Paget's disease, rickets and malignant metastases, there is a proliferation of osteoblasts and new formation of bone. The sedimentation rate is also increased. Excretion of excessive amounts of calcium in the urine and increase in organic phosphorus is usual. Normally 70 to 90 per cent of the calcium output is in the stools, whereas in von Recklinghausen's disease the calcium is markedly lower than normal in the stools but increased in the urine.

These lesions may effect any age group at any time from childhood to old age. The bones most often involved are the long bones, pelvis, and spine. The prognosis as to life is good.

Roentgenographic changes. The tibia and femur are the long bones usually involved (Fig. 79), although the disease frequently affects all of the bones of the skeleton, producing a softening which may result in pathologic fracture. The widening of the bone marrow and thinning of the cortex has been compared to old decayed wood full of small holes. Large cystlike areas may develop in the medullary cavity; the cystic areas have sharp borders, and the condition is sometimes mistaken for osteomyelitis or bone sarcoma. Decalcification in the bones of the hands and fingers is the rule. This loss of calcium is particularly marked in the terminal phalanges of the fingers so that clubbing may develop, roentgenograms showing partial or complete absorption of the

use of dihydrotachysterol (A.T. 10), about 3 cc. daily, until calcium appears in the urine. After this the dosage is dropped to about 1 cc. three to seven times per week.

Pituitary Gland

The pituitary body, or hypophysis, lies in the fossa of the sella turcica, suspended from the base of the brain by the infundibulum. It is an oval, flattened mass 13 by 8 mm. consisting of anterior and posterior lobes, both presenting complicated functions. The anterior lobe appears to be entirely responsible for growth and sexual maturity, but active hormones are also produced by the posterior lobe.

Hypopituitarism. In certain cases some evidence exists that a disturbed function of the pituitary gland may be a factor in the development of *slipping of the upper femoral epiphysis.* This is particularly true in *Fröhlich's syndrome*—the adolescent boys and girls who are obese and show evidence of delayed puberty (Fig. 81). The muscular system in these cases in flabby and poor. There is softening of the metaphyseal area of the long bones predisposing to a displacing downward and backward of the epiphysis; this plus the stresses and strains of weight bearing in the softened bone may produce the slipping. All cases of slipped upper femoral epiphysis cannot be explained on the basis of dysfunction of the pituitary, but Harris (1950) has shown that epiphyses can be more easily dislodged when an imbalance between the circulating sex and growth hormones is produced.

Hyperpituitarism. This condition is produced by a tumor of the pituitary gland; if it occurs before fusion of the epiphyses to the diaphyses it will give rise to *gigantism,* and if it occurs after bone growth is complete, *acromegaly* will develop.

Gigantism is more common in males than in females. There is a tremendous growth stimulus to the skeletal system. These are the "giants" of the side shows; rarely is the body strength commensurate with the skeletal growth. Usually the extremely tall youths have little resistance and only a moderate amount of physical strength, and they frequently succumb to some intercurrent infection before middle life is reached.

Acromegaly appears usually between the ages of 20 and 30 years and is characterized by a peculiar body configuration involving especially the hands and lower jaw, a coarsening of the facial features and thickening of the lips. The head becomes large with prominent supra-

tissue. Some believe that there may be grave danger in their use, as such a dietary regimen leads to increased excretion of calcium and phosphorus in the urine, thereby favoring renal complications. Adequate

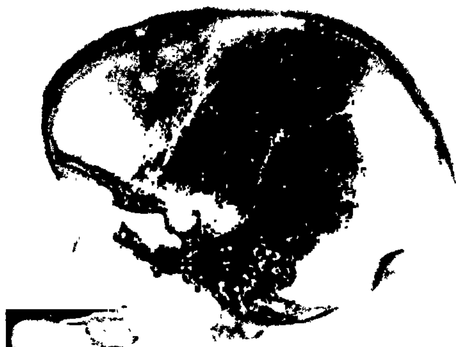


FIGURE 80. "Moth-eaten" skull in parathyroid adenoma (von Recklinghausen's disease; osteitis fibrosa generalisata). The teeth show a characteristic absence of lamina dura

support by braces or by plaster of Paris must be stressed in order to guard against pathologic fracture.

Polyostotic fibrous dysplasia (osteitis fibrosa disseminata; Albright's syndrome), a metabolic bone disease, is discussed in Chapter 16.

Hypoparathyroidism. Hypofunction produces the condition occasionally seen in young children called *tetany* in which both Erb's sign and Chvostek's sign are easy to elicit. The latter can be demonstrated by gently tapping the facial nerve at its emergence from the stylomastoid foramen and, if positive, a twitch of the innervated muscles can be noted. Erb's sign is a neuromuscular response to electrical stimuli. When these motor nerves are stimulated, they respond to a much weaker stimulus than normal.

Tetany can usually be controlled by intravenous injections of calcium; this should be augmented by a high vitamin D diet. The purpose of treatment is to raise the low level of the serum calcium to normal without obtaining a hypercalcemia. Albright (1947) recommends the

orbital ridges. The lower mandible is particularly affected, producing a square, protruding jaw with widely spaced teeth, and the hands become spatulous in type. By roentgen film (Fig. 82), the sella turcica appears enlarged in about 90 per cent of the cases.

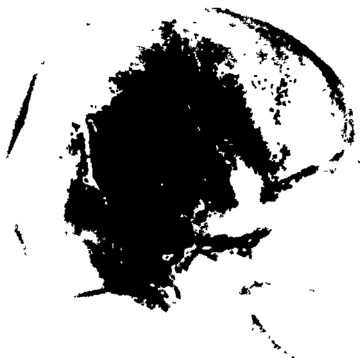


FIGURE 82. Acromegaly. Note enlarged sella turcica with hypertrophied lower jaw.

At times, radiation therapy may reduce the growth of the adenoma and should be tried. Surgery is a difficult and often hazardous method of treatment. Cushing (1912) has described many varieties of pituitary tumors arising from, or in the neighborhood of, the sella turcica which gave startling growth changes at times.

Adrenal Glands

The adrenal glands are small flattened bodies, yellowish in color, immediately above and in front of each kidney. They are usually about 2 by 4 cm. in size. Inside the surrounding capsule is the cortical and medullary portion. Orthopaedic interest lies in a very rare and malignant tumor called neuroblastoma (Chapter 16) which arises from undifferentiated tissue found in the medulla of the adrenal. This

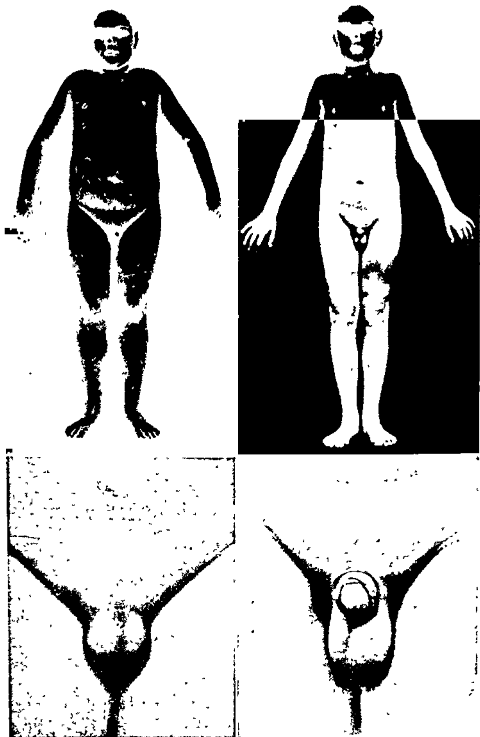


FIGURE 81 Adiposogenital dystrophy (Frohlich's) in a boy 12 years of age. *Left,* before treatment. *Right,* five months after receiving rather small doses of A P.L. (100 rat units three times a week) together with a dietetic regimen and small doses of thyroid extract Note the marked change in his bodily configuration and the definite development of the external genitalia, before treatment the penis was almost completely hidden by the skin fold (Courtesy of Dr. George B. Dorff, from Wolf, *Endocrinology in Modern Practice,* Philadelphia, W. B Saunders Co., 1940.)

Rickets

Rickets is a systemic nutritional disease of infancy and early childhood caused by a diet deficient in vitamin D or by a lack of absorption of vitamin D. The most noticeable orthopaedic effects of the disease are softening and bowing of the long bones, enlargement of the epiphyseal regions of the long bones and prominent bosses of the skull. Active rickets is today rarely seen in orthopaedic practice.

Pathology. The long bones, the ribs and the skull are primarily affected. The cartilaginous epiphyses are thickened, ossification is irregular and the periosteum thickens while the bones underneath ossify imperfectly, giving rise to softening of the shaft and delayed ossification. In the skull the fontanels remain open for a long time, and the

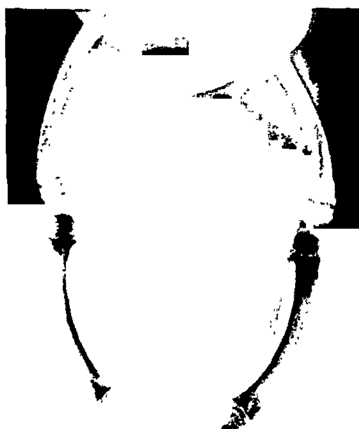


FIGURE 83. Evidence of active rickets. Note cup-shaped appearance in the metaphyseal areas.

thin bone over the growing brain may crackle like parchment under the finger (*craniotabes*). The forehead is broad and the bosses of the head prominent. The spleen and liver are usually enlarged, the muscles are flabby, and anemia is constant. The ribs show characteristic beading, the so-called *rachitic rosary,* also, due to the pull of the diaphragm

tumor widely metastasizes to bone, affecting the skull, pelvis and the long bones in the metaphyseal area. They occur in children under the age of 5 years and have been described under Hutchinson's syndrome.

BONE CHANGES OF DEVELOPMENTAL AND METABOLIC ORIGIN

The skeletal system of the body is not an inert structure but one that responds to the demands made upon it within certain pattern limits. Julius Wolff's (Wolff, 1892) careful study of the structural architecture of the neck of the femur in 1868 permitted him to evolve what is known as Wolff's law, which is "Every change in the form and function of bones, or of their function alone, is followed by certain definite changes in their internal architecture, and equally definite, secondary alterations in their external conformation, in accordance with mathematical laws" (Keith, 1919). However, it was not until some years later that the result of muscle pull upon the underlying bony framework was recognized as the fundamental cause of this internal bony change, although it had been known that the bones and their tuberosities thickened in response to heavy physical labor.

Normal development of bone follows a rather set pattern as regards shape, even though occupation, race and climate may cause certain minor modifications. The tempo of body repair is a changing one, depending in general upon the age of the individual. In the normal infant, a few weeks will suffice to produce abundant callus about the site of the fracture, and nonunion following trauma is practically unknown, although it is a problem in the elderly patient. An imbalance of the chemical constituents of the blood, particularly the blood calcium, phosphorus, phosphatase and protein content, will also affect the repair and structure of bone tissue.

Abnormal bone development of congenital origin is represented by such diseases as chondrodystrophia foetalis, osteogenesis imperfecta or pseudarthrosis of the long bones; whereas in deficiency diseases such as rickets and scurvy and in those of endocrine disturbance such as cretinism and gigantism, deformities are produced in the developmental stages of bone after birth. In some of these the osseous changes are evidenced primarily by disturbance in the epiphyseal growth with subsequent distortion of the shaft. After childhood and the fusion of the epiphyseal cartilages, we have other affections of the long bones that make their appearance in adult life.

As the patient stands, the general weakness is particularly obvious in the poor body posture with its pot belly, lordosis, knock-knees, bowlegs or flat feet. Even before the child stands, an abnormal bowing of the femora and deformities of the tibiae may be produced (Fig. 84). Anterior bowing of the tibiae may be sometimes due to the mother's habit of holding the child on the edge of her lap and allowing the feet and lower legs to project over her thigh, thus producing an an-

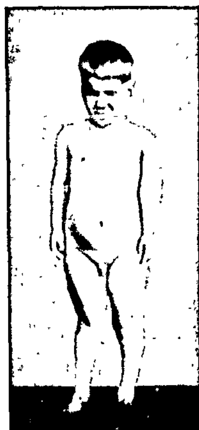


FIGURE 84. Mild rachitic deformities with pot belly, right knock-knee and left bowleg

terior bowing. This type of bowing may in later life be confused with luetic "saber shins." In cases with delayed walking some pain and marked muscular weakness occur. *Coxa vara* (lessening of the angle of the head and neck with the shaft of the femur), because it is concealed by the thick muscles of the hip, may be overlooked but should always be kept in mind as it is a most disabling deformity which needs correction. The simplest method of detecting coxa vara clinically is to note whether there is any limitation of abduction at the hip; and, if so, roentgenograms should be taken to decide the degree of coxa vara

muscle on the softened ribs, there is a depression running laterally from the xiphioid process, the so-called *Harrison's groove*. However, the deformities are most typical in the long bones of the lower extremity; these become bowed through their underlying softening. The pelvis may become narrowed and deformed and the spine bowed from muscle weakness. The metaphyses of the long bones are broad and appear saucerized in the roentgenogram (Fig. 83), presenting pointed lips at the margins, hook-shaped in appearance. The stage of bone softness and general muscular weakness may be followed by one of repair which rapidly changes the picture. The softened bones become hard and premature ossification occurs at the epiphyseal junctions.

Clinical Picture. The early symptoms of active rickets are restlessness at night, constipation and head sweating. The child has a prominent abdomen (pot belly), and often the head is larger than normal. Examination of the epiphyses of the long bones shows them to be swollen and tender, especially at the wrists and ankles.

At times, due to muscular weakness, the child may be unable to stand or walk, the small and flabby muscles being suggestive of infantile paralysis.

Metabolic Studies. A general disturbance in the calcium and phosphorus metabolism is found in active rickets, their concentration in the blood serum being below normal. Normal findings are 10 to 11 mg. per 100 cc. of calcium and 4.5 to 6.5 mg. per 100 cc. of phosphorus. Although the serum calcium may remain normal and the inorganic phosphorus low, the balance of the two is upset. In rachitic infants the inorganic serum phosphorus is usually reduced to between 1.5 to 3.5 mg. per 100 cc. In active rickets, the greater part of the ingested calcium and phosphorus is excreted in the stool so that the skeletal system is depleted.

Rachitic Deformities. The bony deformities in rickets result from softened bones. The dorsal kyphosis of rickets is an exaggeration of the normal curve which develops in those infants who sit upright a greater part of the time. It is simply a sagging of the entire spinal column due to muscular weakness, but the underlying vertebrae become misshapen so that the condition can be sometimes mistaken for Pott's disease. The danger lies in continuing the upright attitude until the deformity becomes a fixed one. Recumbency on a frame followed by general constitutional care will correct the abnormal dorsal curve. Another complication in the rachitic spine is the development of scoliosis, which may become a fixed curve in later life.

In rachitic coxa vara, during the early stages wide abduction of the limbs on splints may restore the normal neck angle, but in older cases in which the deformity is fixed, a wedge osteotomy made at the level of the lesser trochanter and wide abduction of the distal fragment restores the head, neck and shaft angle.

Genu valgum and *genu varum* (knock-knees and bowlegs(are often seen as the result of rickets. When the bone is soft enough to respond to the molding force of braces or plaster, these deformities may be corrected without operation.

Osteomalacia

Osteomalacia is a deficiency disease and represents an adult avitaminosis, resulting in softening of the bones. In this country it occurs

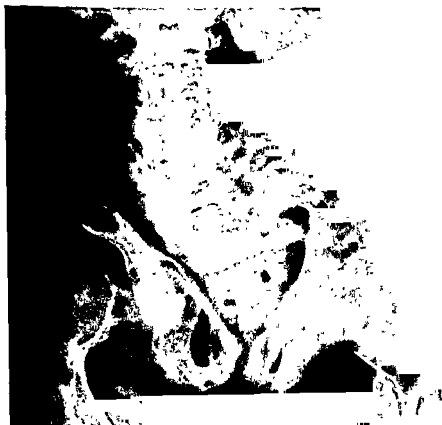


FIGURE 85. Osteomalacia. (Courtesy of Colonel Philip Hodes.)

rarely but has been reported following pregnancy. It is seen much more frequently in the Orient and is the adult form of rickets.

The serum calcium, phosphorus and protein tend to be low, though one of these will tend to be strikingly low. Usually an increase in

present. This deformity in rickets is usually bilateral and may at times be present to an extreme degree.

Other causes of coxa vara are nonrachitic and are more commonly encountered in the later age periods, such as adolescence, when an epiphyseal slipping may be noted which gives rise to this deformity. This form is due not to a softening of the entire osseous structure of the hip joint, but rather to a definite dissolution of continuity at the epiphyseal line, and it is discussed in Chapter 9.

Late rickets. Deformities develop in late childhood or adolescence, but this disease is rarely seen. The orthopaedic treatment consists of correction of the deformities by means of osteotomies.

Renal rickets. This disease is sometimes encountered in cases of chronic nephritis in childhood. It may present the deformities of infantile rickets. Roentgenograms show irregular metaphyseal ossifications with little tendency to the broadening of the metaphysis characteristic of the rachitic type of bowing.

Clinically it is marked by a dwarfed or stunted growth. Beginning in childhood, periods of drowsiness, vomiting, headache and polyuria with always an advanced bilateral interstitial nephritis are present. It is uniformly fatal and no beneficial treatment is known. Vitamin D is of no avail.

Treatment. An antirachitic diet consisting of adequate calcium, phoshorus and vitamin D, together with sunshine and fresh air, will cure acute rickets. Cod liver oil or viosterol, milk and green vegetables in abundant amounts should be given. When skeletal deformities have made their appearance, orthopaedic measures are indicated. During the acute stage the spine should be relieved of the stresses and strains of weight bearing by recumbency. If the lower extremities are primarily involved, wedged plaster casts or properly fitting braces will usually permit correction of the bowing of the legs up to about the age of 3. After this age radical treatment is necessary.

After the active stage of rickets, the bones become recalcified and hardened sufficiently to resist conservative treatment; then an osteotomy is advisable, and is particularly necessary in the late cases. This consists of fracturing the bone at the level of the greatest degree of deformity by a transverse osteotomy, or removal of a wedge from the outer (convex) side of the curve, to correct the bowing. This is followed by immobilization in plaster for 6 to 10 weeks or until the roentgenogram shows an adequate amount of firm callus. Gradual return to weight bearing may then be permitted.

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rarely but has been reported following pregnancy. It is seen much more frequently in the Orient and is the adult form of rickets.

The serum calcium, phosphorus and protein tend to be low, though one of these will tend to be strikingly low. Usually an increase in

alkaline phosphatase occurs as well as deficient absorption of the ingested calcium, phosphorus and protein in foodstuffs. The vitamin D deficiency must be corrected.

Pathology. The bones become soft and severe deformities may develop in the pelvis, thorax, spine and long bones. The cortex is thin and shell-like and the marrow cavity is enlarged.

Clinical Picture. The condition may be mild or severe. The patient may complain only of general weakness and slight pain, or the bone changes may be marked giving rise to severe backache, sometimes accompanied by compression fractures. The roentgenograms (Fig. 85) show generalized osteoporosis with or without bony deformity.

Prognosis. Osteomalacia responds to adequate treatment promptly, resulting in recalcification, but the deformity is permanent.

Treatment. A diet high in calcium, phosphorus and protein, with vitamin D, should be given; that is, rich in milk, cheese, nuts and eggs plus vitamin D concentrate. Orthopaedic protection to the skeletal system by braces is advisable.

Myositis Ossificans

There are two types of myositis ossificans: the progressive and the frankly traumatic.

Progressive Myositis Ossificans. In progressive myositis ossificans we have a disease of unknown etiology, characterized by the progressive formation of bone in muscles, tendons and ligaments which eventually leads to severe impairment of function and stiffness of the adjacent joints. It generally starts before the age of 10, and males are more often affected than females.

The disease apparently starts with a fibrositis which contracts to form a firm mass in and about the muscle fibers, followed by calcification and later ossification. During its acute stage, fever, local tenderness, pain and edema are present. Shortly following this a slow progression occurs until extension of the ossification may produce ankylosis and complete restriction of physical activity. The prognosis is poor for complete arrest of the disease, but remissions and exacerbations may occur. Death is usually caused by some intercurrent infection.

Excision of certain of the bony deposits is advisable during the chronic stage if it is thought it will improve the function of the part. Flexion and adduction contractures of the joints can slowly be overcome by judicious traction, stretching and tenotomy unless complete ankylosis has ensued. There is always danger that surgical removal of

the bony masses may be followed by more bone deposition in the same region.

Traumatic Myositis Ossificans. The local traumatic form of myositis ossificans is induced by repeated injury or strain to a particular portion of the body. Bone formations occasionally form in the adductor muscles in those accustomed to riding horseback a great deal (rider's bone). These bone masses can be dissected out if they give rise to disability.

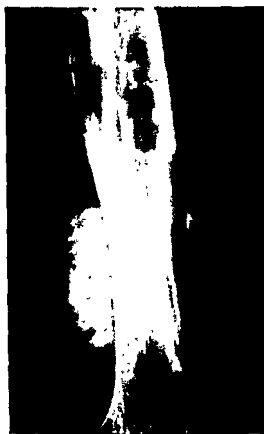


FIGURE 86. Traumatic myositis ossificans. This followed femoral fracture which was not immobilized.

The traumatic form may also follow muscle tearing from bone, with stripping of the periosteum. The most common sites are about the brachialis anticus muscle in elbow fractures, and the quadriceps extensor muscle in injuries about the knee. Manipulation of a recently fractured elbow increases the opportunity for myositis ossificans to occur. Therefore, in children forced passive motion or deep massage is always distinctly contraindicated following fractures in these areas (Fig. 86).

After the traumatic type of myositis has developed, rest of the part and the avoidance of surgery is indicated for at least 1 year. Absorptive doses of diathermy may be of some value. Only after roentgeno-

grams show that the newly formed bone margins are smooth and that the process is inactive, certainly not under six months following injury, can excision of the offending bone formation be considered.

Scurvy

Scurvy is a constitutional disease due to a deficiency in antiscorbutic vitamin C, which is found in citrus fruits, unboiled milk and fresh vegetables. Its continued deficiency gives rise to great debility and is accompanied by swollen, bleeding gums. Scurvy may occur at any age and was formerly very common in sailors when they were denied an adequate balanced diet. We know now it is prevented by adequate amounts of vitamin C in the diet.



FIGURE 87. Scurvy Note stripping up of periosteum with ossifying hematoma.

Clinical Picture. Today the disease occurs usually in infants between 6 and 18 months of age, manifesting itself by extreme weakness and well-marked subperiosteal hemorrhage about the long bones (Fig. 87) or large subcutaneous extravasations of blood. The gums become swol-

len and bleed easily; in adults teeth may even fall out. The breath always has an extremely fetid odor.

Treatment. The food deficiency is supplied by adequate amounts of orange, lime or tomato juice. Whether in a child or an adult, correction of the diet produces improvement and the prognosis for complete cure is excellent. Complete rest with protection of the affected and sensitive extremities by simple splints may at times be helpful. The tenderness and unwillingness to move the limbs may cause the disease to be mistaken occasionally for infantile paralysis. The early symptoms may resemble rheumatism, for the painful joints are sensitive to pressure and may be somewhat enlarged, but evidence of inflammation such as local heat and redness is lacking. After the acute stage, very gentle massage to the limbs may be helpful and is to be recommended. The disease is rarely seen today.

Hemophilia

Hemophilia is a hereditary disease characterized by a prolonged blood-clotting time. Its etiology is unknown, but it is transferred to males from generation to generation through the females. It is of orthopaedic interest because it gives rise to hemarthrosis following some slight injury, and its presence is a contraindication to any avoidable surgery.

Clinical Picture. Simple contusions or scratches may initiate serious hemorrhage, and the bleeding throughout the soft tissues, especially the muscles, may last indefinitely; the bleeding is of a persistent oozing nature that leads toward profound anemia. There is some local heat accompanied by pain and marked disability, so much so that the condition has been mistaken for tuberculous arthritis. The diagnosis depends upon a family and personal history of repeated bleedings following slight trauma, as well as the finding of a delayed blood-coagulation time.

Treatment. In those suspected cases requiring operation, the patient must be conditioned by repeated preoperative transfusions and the injection of thromboplastic material. Intramuscular administration of placental extract has been reported effective, as has the use of histamine. Although this condition has no cure, male children from hemophilic fathers should be guarded against trauma.

The knee is most commonly affected. Hemarthrosis can be temporarily relieved by aspiration and a pressure bandage applied to the limb. In the joint subjected to repeated hemorrhage certain irritative reac-

tions are set up with interference to joint function, the typical roentgen appearance of a chronic atrophic arthritis developing. Rest and protection of the acutely affected joint, combined with ice caps, may produce some absorption. Following the acute stage, the patient should be fitted with a long leg brace with restricted knee motion. Despite proper treatment there is frequently some permanent restriction to motion.

Achondroplasia

Achondroplasia (chondrodystrophia foetalis) is a condition characterized by bony maldevelopment which gives rise to a disproportionately long trunk with short arms and legs. It was first accurately described





FIGURE 88 Chondrodystrophia foetalis The characteristic features are a long trunk and short extremities

FIGURE 89. Chondrodystrophia foetalis Bone-growth distortion in the same case.

by Parrott in 1890. These patients are frequently seen in circuses and are easily recognized by their large head and short stature (Fig 88).

Etiology. This disease is apparently due to a defective development of the enchondral ossification. The condition is congenital and sometimes definitely inherited. The gross appearance of the child sometimes suggests rickets, but as a rule these achondroplastic dwarfs should be recognized without difficulty.

Roentgenographic Findings. Roentgenograms show characteristic changes. The long bones are short and broad with some degree of irregularity. The epiphyseal lines and metaphyseal areas tend to broaden out of proportion to the length of the bones, and the vertebral bodies become shaped like a biconcave lens. The effects are widespread so that the diagnosis is simplified by examination of the entire skeleton. Slow growth of the epiphyseal bone, and sometimes complete arrest of growth, is characteristic. The changes noted on the roentgen plate are largely at the ends of the bone, which show distorted osteochondral growth (Fig. 89).

Chondrodystrophia Calcificans Congenita

Another form of chondral growth disturbance, chondrodystrophia calcificans congenita, has been reported by Hünermann (1931). This



FIGURE 90. Chondrodystrophia calcificans congenita (Hünermann).

rare condition is found in infants and was first called attention to by Fairbank (1927) and later (1949) given by him the name "dysplasia epiphysialis punctata." The cause is unknown and the diagnosis depends on the roentgenogram (Fig. 90). The stippling effect becomes less striking about the epiphyses as the child grows older. It affects females twice as often as males.

Treatment. Occasional need may arise to correct some of the gross skeletal deformities by braces, but usually no treatment is indicated. These patients rarely live beyond the age of 12 months, the causes of death being kidney or lung infection.

Dyschondroplasia (Ollier's Disease)

The term "dyschondroplasia" was used by Ollier (1899), who appears to have been first to recognize the disease. The term meant a dis-



FIGURE 91. Ollier's disease showing distribution of bone lesions. The condition largely affects one side.

turbance of the growing ends of bone in which the normal ossification of cartilage fails to take place. As the bone increases in length there will remain in the diaphyseal area cartilage cells which would ordinarily undergo ossification. Although the condition shows a tendency to be unilateral (one-third of all cases), the case which Ollier originally described was not strictly unilateral, since both hands were involved. The etiology of the condition is unknown and the distribution of the lesions at the ends of the long bones seems to follow the course of the branches of the nutrient artery.

Treatment. There is no treatment other than correction of the bone deformity by osteotomy when it seems indicated. Bowing of the tibia and radius (Fig. 91), if interfering with function or for cosmetic reasons, may be improved by fracturing and straightening the bone.

Diaphyseal Aclasis (Hereditary Multiple Exostosis)

This congenital disorder of growth presents osteocartilaginous exostoses and is sometimes also classed as *multiple cartilaginous exostosis.* It is frequently seen in orthopaedic practice and affects males more often than females. It appears to be related to Ollier's disease. There is a definite hereditary tendency and the disorder occurs among antecedents or relatives in about 65 per cent of the cases.

Pathology. The growth disturbance at the diaphyseal ends of the long bones is most marked where the growth length is the greatest, the condition representing a failure of the growing ends of the long bones to model normally. Many of these bone outgrowths do not manifest themselves until puberty. These exostoses always point away from the adjacent joint. They are club-shaped with an expanding portion which is covered with a cartilaginous cap; a bursa often forms between this and the overlying soft structures. Broadening of the metaphysis is essential to a diagnosis and the histologic picture shows signs of irregular ossification. These tumors usually increase in size during the active growth period and have been reported as undergoing malignant change at this time; the latter rarely occurs.

Clinical Picture. These osteocartilaginous bony masses, varying in size and shape, may be single but are usually multiple and arise near but not from the adjacent joint surface. Many regions of the skeletal structure are involved; if they happen to be well protected by the overlying muscles they may give rise to no discomfort. In the older child, growth disturbances of the adjacent bones may be due to the

retardation in growth of the affected one. A deformity may also develop in the adjacent joint, such as might be produced by an asymmetrical growth of the tibia and fibula (Fig. 92).



FIGURE 92 Multiple cartilaginous exostosis (diaphyseal aclasis)

Treatment. For cosmetic reasons, or if the exostoses render the part more liable to injury from without, or injury by pressure on adjacent structures, operation is indicated. When the exostosis is removed, complete excision of the entire bony tumor along with its base must be done.

Fragilitas Ossium (Osteogenesis Imperfecta; Brittle Bones)

Fragilitas ossium is a rare congenital disease of the bones which is distinguished by frequent fractures, and in the hereditary type by blue sclera It most commonly affects females, and the inheritance factor seems to be a dominant characteristic. Both thymus and parathyroid adenopathy have been suggested but not proved to be the cause.

Clinical Picture. A history of frequent fractures calls attention to this affection, the marked fragility of the bones usually being noticed early

in life. In the hereditary type the fractures and deformities may develop *in utero;* the children are generally helpless, deformed cripples. The china blue color of the sclera (Fig. 93, opposite page 126) is always to be looked for in suspected cases, but it may not be present in the nonhereditary type. It is supposed to be due to a decreased opacity of the sclerae permitting the pigmentation of the deeper coat to be seen.

Prognosis. As regards healing of the fracture the prognosis is excellent, but in the majority of cases the patients are stunted in growth and are disabled by their susceptibility to multiple fractures. If they can be protected through adolescence their susceptibility to fracture lessens and they can be expected to lead a restricted but fairly normal existence. They should be told that if they have children approximately one-half of them may develop the disease. The blood chemistry is not unusual. More than ordinary care should be taken to avoid fractures, but there is no known specific therapy for the disease. *Deafness* is a frequent complication in the older cases, but usually does not appear before the third decade.



FIGURE 94. Albers-Schönberg disease (marble bones).

Albers-Schönberg Disease (Osteopetrosis; Marble Bones)

Albers-Schonberg disease is a rare disease characterized by an increased density of some or all of the bones in the skeletal system due to an increased deposit of lime salts in the affected bones. The patient may complain of persistent pain in the bones. Roentgenograms (Fig. 94) show a marble-like appearance of the bones with thickening of the cortex and loss of the medullary canal. No etiologic factor is known and all treatment has proved unsatisfactory.

Melorheostosis

Melorheostosis is a very rare condition which affects the skeletal system, although the skull, spine or ribs are rarely involved. The typical features, all of which may or may not be present in the individual case,



FIGURE 95. Melorheostosis. Note characteristic "candle drippings" affecting some of the carpal and metacarpal bones. (Courtesy of Colonel Oscar Reeder.)

are: (1) pain in the region of the affected bone or bones, which is usually confined to one limb; (2) progressive distortion of the bone due to its thickening, with accompanying limitation of joint motion; and

(3) the striking roentgenographic appearance (Fig. 95), which was originally described by Leri and Joanny (1922) as the "flow of candle grease down the limb," by others as "candle drippings."

It probably always begins in childhood, although the majority of cases reported have been noted in the first three decades, and the metaphyseal and epiphyseal regions are most involved. The cause of the bone petrosis is unknown. Blood examination has revealed nothing of importance.

The most frequent complication is one of scleroderma and fibrosis of the surrounding soft tissues. The latter is a factor in the joint limitation noted.

Fairbank (1927) reviews the pathology of the dense streaked areas and concludes that they are sclerotic, the lamellae being arranged in a compact bizarre manner with an interlacing pattern of immature and adult bone. In a few cases a definite fibrosis of the marrow was observed.

Osteopoikilosis (Osteopathia Condensans Disseminata)

Osteopoikilosis is a rare bone affection in which multiple spotty cancellous areas pepper the epiphyseal and metaphyseal regions of any bone in the body, but are more frequently seen in the pelvic, carpal and tarsal bones.

The cause is unknown, but males are affected twice as commonly as females. It is thought to be congenital, but it has been found at all ages and it gives rise to no symptoms. It usually is discovered by a chance roentgenogram.

Fairbank (1948) believes that the roentgenographic appearance (Fig. 96) does not change once the individual has attained bone growth, and states that several cases have been associated with dermatofibrosis lenticularis disseminata. It has also been associated with melorheostosis, but usually the diagnosis will be made clear by roentgenograms.

Infantile Cortical Hyperostosis

Infantile cortical hyperostosis is a rare condition of the bone that is seen early in the first year of life, as early as the third week, and as late as the twentieth month. Its orthopaedic interest lies particularly in the fact that, when it affects only one bone, it may clinically be confused with a primary malignant bone tumor in infancy.

Etiology. The cause producing the underlying bone change is un-

known. A virus or bacterial infection has not been proven to date, nor has any direct relationship to syphilis or scurvy been found. Its quick onset is suggestive of an allergic phenomenon, but no proof exists. It is closely related to avitaminosis, although when appearing

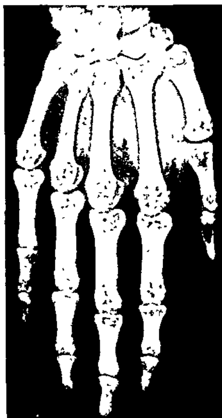


FIGURE 96 Osteopoikilosis Note characteristic "spotty" features on hand and wrist.

in the first six months of life other causes must be sought. In the very young patients seen all serologic tests have been negative for syphilis and no evidence of infection or nutritional deficiency has been found. Biopsies reveal only hyperplasia of bone.

Clinical Picture. Tender swellings of the face and jaws, the scapular region or one or both extremities are often found. Usually multiple bone lesions are present There is no increased local heat and rarely does a temperature reaction accompany the tender swellings which appear quickly and disappear slowly.

Roentgenographic Findings. Cortical thickenings (Fig. 97) in the long bones, leaving the terminal segments unaffected and occurring in infancy without other known etiology, are suggestive of this condition. There is a hyperplasia of lamella cortical bone without evidence

of any inflammatory reaction or subperiosteal hemorrhage. After several months, occasionally longer, the bone thickening gradually diminishes or may almost disappear, although some cortical thickening usually can be recognized in the condition long after the tenderness and gross swelling have left.



FIGURE 97. Infantile cortical hyperostosis in a child of 13 weeks (*left*). Five months later (*right*) rapid bone change was noted. Still later, the bone pattern was completely normal.

Treatment. Protection to the affected part should be provided during the acute phase. There is no known specific therapy (Caffey, 1939; Caffey and Silverman, 1945; Miller and Ostrum, 1945) but time almost completely restores the bone pattern

Morquio's Disease (Osteochondrodystrophia Deformans)

Morquio's disease is a deformity of the skeletal system characterized by dwarfism, disturbances of the growth centers (Einhorn *et al.*, 1941) and a subnormal mentality. A large proportion of the cases occur in males.

In many instances the condition has been confused with achondroplasia or familial rickets and has not been noticed until the child begins to stand or walk Many children are unable to walk and the muscular weakness and physical disability are striking features. There is usually marked restriction to joint function and the characteristic

picture is a dwarflike figure with a normal sized head on a short neck. Protrusion of the sternum on which the chin almost seems to rest, scoliosis, dorsal kyphosis and more or less useless lower extremities are the striking features. It is a hereditary disease transmitted as a recessive characteristic.

Roentgenographic Findings. The diagnosis rests largely upon the roentgenographic features. The epiphyses are irregular and misshapen, and sometimes absent. The whole spine partakes of the deformity and the shafts of the long bones are thin, showing areas of uneven *density and rarefaction.*

Treatment. There is no known specific treatment. Braces may be used in preventing and correcting the deformities of the back and extremities; occasionally osteotomies to correct the bony deformities are helpful.

Arthrogryposis Multiplex Congenita

This rare condition presents a congenital limitation of motion in all the joints of the body except the maxillary joints and the vertebral column. It was described as a separate clinical entity by Stern (1923). There is a characteristic rotation deformity of the arms, inward, and of the thighs, outward. The soft tissues surrounding the joints are thickened and active and passive motion at the joints is limited to a few degrees There seems to be a widespread congenital dysplasia of the muscular system The children are mentally and physically underdeveloped *and lend themselves badly to any corrective measures. The* Möbius syndrome may be a type of arthrogryposis limited to the facial musculature, both stemming from a primary mesenchymal defect.

Accompanying the generalized deformities of the extremities there are present usually other congenital anomalies such as clubbed hands and feet and dislocation of the hip

Treatment. Due to deformation of the soft tissues, especially the muscle deficiency, no treatment is curative and when the deformities are corrected they have a great tendency to recur Some little improvement from stretchings, tenotomies and fasciotomies may be expected, but even after the deformities are lessened the muscle power is so slight that satisfactory joint function cannot usually be anticipated.

Injuries

SOFT TISSUE INJURIES

A *sprain* is a partial or complete rupture or stretching of one or more ligaments about a joint. A *strain* is an injury to a muscle, tendon or the fascia over the muscle. These two types of injuries are common, with sprains occurring more frequently than strains.

Sprains

The tearing of one or more ligaments about the joint may be produced by a sudden twisting or wrenching of the joint. An increase of synovial fluid in the affected joint, with hemorrhage into the synovial membrane and the loose periarticular tissues, may follow this painful injury. These conditions are discussed under the individual regions, but certain fundamental principles are common to all regions.

Treatment. The sprain injury must be localized very accurately. Immediate treatment should be directed toward controlling hemorrhage and extravasation of fluid into the surrounding tissues. Efforts should be made to hasten absorption of the fluid and to prevent a repetition of the injury. The joint must be protected against those movements that permit a pull on the injured ligaments.

Shortly after the injury, a proliferation of fibroblasts and infiltration of lymphoid cells near the bony attachment of the ligaments will be found. If rupture of the ligament is accompanied by a dislocation or fracture of the joint, obviously reduction of the displacement is the first step in the treatment. If there has been no dislocation or fracture, early *application of cold compresses to the limb, rest, elevation of the* part and employment of a compression bandage are of value. In some cases of ankle sprain uncomplicated by fracture or dislocation, local application of ethyl chloride spray with the active use of the part has proved of value. It is important to remember that passive movement, in an attempt to prevent subsequent stiffness, many times aggravates the condition, whereas active movement, within the limits of pain, will aid in a natural recovery. Not until the active stage of the acute condition has subsided, and *only then*, should passive movement be instituted. This must be done judiciously by gently moving the affected part through a complete range of motion once, and only once. Baking and massage may be useful, although in the very early stages of a sprain the application of heat to an injured joint is best delayed.

Strains

In strains, the tissues are actually torn at some point between the origin and the insertion of the muscle. The picture of hematoma formation with absorption and healing by fibroblastic repair is presented. The clinical picture, as in the sprain, is one of pain and swelling. If the injured person is not seen promptly, the swelling may be rather diffuse.

Treatment. Rest of the incompletely torn muscle or tendon in its relaxed position is essential; immediate surgery is indicated if the tear is complete. If only a small number of the muscle fibers are torn, an adhesive strapping can be applied to act as a local splint. Baking and massage with contrast baths are also sometimes useful. A contrast bath, which consists of plunging the injured part for a fraction of a second alternately into hot and cold water, produces an increased blood flow and hastens the process of repair. Short-wave diathermy is also an effective method of promoting hematoma absorption.

FRACTURES

A fracture is a dissolution of bony continuity, with or without displacement of bone fragments, and is accompanied by soft tissue damage of varying degree

Clinical Picture in Fresh Fractures. The history of the accident — how, when and where the injury was received — may cause one to suspect a fracture

Inspection reveals obvious local swelling, and often ecchymosis and gross deformity of the part. The patient usually complains of pain at the site of fracture and palpation reveals an abnormal mobility and crepitus as well as impairment of function.

In all injuries to bones and joints, roentgenograms must be regarded as essential A careful examination will in many instances make the diagnosis certain, but the type of fracture, whether it is transverse, oblique, comminuted, or of other nature, as well as the displacement of the fragments and their relationship in regard to soft tissue damage and their proximity to joint articulation, can best be accurately determined by roentgenogram In addition to this the roentgen film is a permanent record that may be of definite legal value later. At least two exposures, the anteroposterior and lateral views, are essential. In the more difficult cases in which the clinical symptoms are suggestive

of a fracture but routine views do not disclose it, oblique views should always be taken.

Types of Fracture. The *simple* fractures are those in which there is no break in the skin, whereas the *compound* fractures are those in which there has occurred a break in the skin through which the bone ends may or may not be protruding at the time of the examination. To this Conwell (1947) has added the term "complex simple frac-

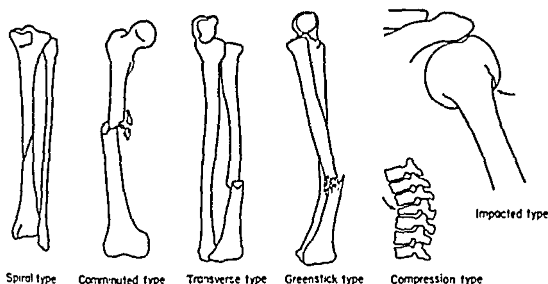


FIGURE 98. Common types of fracture.

ture," meaning a simple fracture that has received severe trauma to the surrounding soft structures. If the bone is not completely broken, it is an *incomplete* fracture, which may be the *greenstick* variety (Fig 98) in children, or a *fissure* fracture, which is seen extending parallel to and along the shaft of the long bone. A crushing type of incomplete fracture which occurs in the skull consists of fracture of the outer table. Crushing of the body of a vertebra results in *compression* fracture. The *complete* type of fracture, in which the bone is broken completely across, may be transverse, oblique, spiral, comminuted, or impacted (see Fig. 98). When a fracture occurs through an area of disease it is classed as a *pathologic* fracture

Repair of Fractures

Both clinical and experimental evidence supports the view that the repair process following fracture is a local phenomenon. The results of feeding selected diets or of using vitamins, endocrines or various drugs have been reported upon extensively as well as studies on the

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FRACTURES

A fracture is a dissolution of bony continuity, with or without displacement of bone fragments, and is accompanied by soft tissue damage of varying degree.

Clinical Picture in Fresh Fractures. The history of the accident — how, when and where the injury was received — may cause one to suspect a fracture.

Inspection reveals obvious local swelling, and often ecchymosis and gross deformity of the part. The patient usually complains of pain at the site of fracture and palpation reveals an abnormal mobility and crepitus as well as impairment of function.

In all injuries to bones and joints, roentgenograms must be regarded as essential. A careful examination will in many instances make the diagnosis certain, but the type of fracture, whether it is transverse, oblique, comminuted, or of other nature, as well as the displacement of the fragments and their relationship in regard to soft tissue damage and their proximity to joint articulation, can best be accurately determined by roentgenogram In addition to this the roentgen film is a permanent record that may be of definite legal value later. At least two exposures, the anteroposterior and lateral views, are essential. In the more difficult cases in which the clinical symptoms are suggestive

the tissues and extravasated blood about the bone ends depends upon the number and the size of the blood vessels ruptured. After the first momentary sharp pain of fracture the part for the next 20 to 30 minutes is in a state of local shock, with marked flaccidity and muscle relaxation; the limb is temporarily numb. This is the "golden period" for reducing and splinting the fracture. Early adequate treatment at this time, when there is little or no pain to the patient, makes definitive care a much simpler problem.

Following this short interval sensation returns. The contused muscles contract and go into spasm. Any movement of the part is painful. Overriding frequently follows when the fracture involves a long bone. This produces increased deformity and additional interference with the vascular and lymphatic circulation.

Repair of Shaft Fractures. In the large long bones, because of the size of the blood clot, a long period is necessary for organization and absorption, and the steps of fracture healing 3 to 6 weeks after injury can be traced at different stages (Fig. 99). The periphery of the blood clot shows further advance in the healing process than the center. Considerable time is needed for a firm callus to be formed in fractures of the large bone.

Organization of hematoma. At the time of fracture, blood from the injured vessels of the marrow, periosteum and surrounding soft tissues form a hematoma, and organization of the clot with invasion by connective tissue begins within a few hours. When the hematoma is extensive and reduction delayed beyond the early stage, the muscles become infiltrated and are converted from elastic, extensible structures into lardaceous, semisolid masses which interfere with reduction of the fracture. The remaining fluid portions of the clot seep to the surface along the muscle planes, giving rise later to the "black and blue" appearance of the skin; this subcutaneous hemorrhage (ecchymosis) may be slight or marked, depending on the degree of tissue laceration. Within the first 24 hours round cell infiltration and lymphocytic accumulation occur and the development of a rich and intricate vascular network begins (Fig. 100).

Fibrosis and calcification. A hematoma produced in soft parts without injury to bone would under ordinary conditions be completely absorbed or replaced by scar tissue. In clean wound healing of soft tissue the term "primary union" is used when there is a minimum of scar tissue formed. The outcome is not fundamentally different when there is a dissolution of bone continuity (fracture). Under favorable

correlation time of experimental animals regarding fracture healing in the presence or absence of some chemical. As yet no conclusive proof has been offered that any of these measures hastens union in a normal animal on an adequate diet. Individual workers have reported a correlation between serum calcium and phosphate values and their interrelationship with fracture healing, but extensive checks have failed to support their views. Certainly the levels of blood calcium, phosphorus and alkaline phosphatase are not significantly or constantly elevated during normal fracture healing.

Depending upon the extent and site of injury, the bone-repair processes may undergo some modification. In a greenstick fracture (incomplete fracture in a child) hemorrhage will be minimal, whereas in the comminuted fracture with displacement the local repair process will elicit much more extensive reaction. Systemic factors, such as debilitating diseases, rickets, osteomalacia, endocrine disturbances and similar affections, influence bone healing very little. The young possess a tremendous power for repair, but this rapid tempo slows down somewhat as old age approaches, although there are individual variations in bone repair.

Following fracture there often is produced a temporary general state of shock. Within a few hours there follows a moderate rise in temperature, an increased leukocyte count and sedimentation rate and an increased basal consumption of oxygen. Major interest, however, should be directed toward a careful consideration of the local problems involved in fracture healing. It is of practical interest to remember that in the shaft or cortical type of fracture, the spiral fracture evokes the greatest response to fracture healing and produces the most massive type of callus, largely because there is a greater area of periosteum stripped up from the underlying cortical bone. The comminuted fracture produces the next greatest response, the least callus formation occurring in the transverse type of shaft fracture. In the cancellous or spongiosa region of the bone no external callus is produced and healing occurs by simple extension through the union of two parallel lines of bone formation This is illustrated in the healing of an impacted fracture occurring in spongiosa tissue and in fractures of the neck of the femur.

What actually happens at the time of fracture? Moderate or severe laceration of the soft tissues occurs at the time the bone is broken. Locally, the soft parts are rapidly infiltrated by hemorrhage and edema, producing an aseptic inflammation. The amount of hemorrhage into



Figure 99. Typical blue sclerotics in fragilitas ossium (osteogenesis imperfecta). Members of every generation of this family suffered multiple fractures from congenital bone fragility. (From Watson-Jones, R., *Fractures and Joint Injuries*, Vol. I, 4th ed. Baltimore: Williams & Wilkins, 1952. Courtesy of E. & S. Livingstone, Limited.)

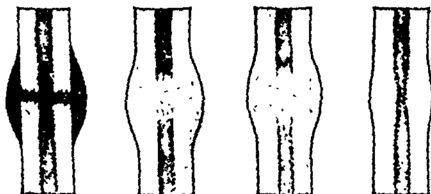


Figure 100. Healing of a perfectly immobilized fracture. The fragments are joined by an uninterrupted growth, in the early stages of granulation tissue, and in the later stages of callus, continuity is established. (From Watson-Jones, R., *Fractures and Joint Injuries*, Vol I, 4th ed. Baltimore: Williams & Wilkins, 1952. Courtesy of E. & S. Livingstone, Limited.)

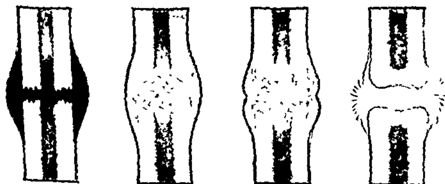


Figure 101 Healing of an imperfectly immobilized fracture. Shearing and rotation strains create a plane of cleavage. Continuity is interrupted and fibrous tissue is laid down parallel with the fractured surfaces. (From Watson-Jones, R. *Fractures and Joint Injuries*, Vol I, 4th ed Baltimore. Williams & Wilkins, 1952. Courtesy of E. & S. Livingstone, Limited.)

conditions callus is formed, which is in reality a bone scar. In bone the undifferentiated connective tissue possesses the power to be transformed into a fibrocartilaginous callus. This usually occurs from the second to the third week and continues on to the time of union.



FIGURE 99. Abundant subperiosteal callus has formed (upper third of photo) in this tibial fracture (young child). The osteoid matrix has been deposited in bars between the extremely numerous blood vessels of the granulation tissue. New bone formation has occurred in the granulation tissue of the intermediate callus (left lower corner). (× 22.) (Scudder, C. L. *The Treatment of Fractures* Philadelphia, W B. Saunders Co., 1938)

Along with the formation and organization of the hematoma about the fracture site there is a change in the pH of the fluid with a shift to the acid side. With the acid pH there develops a decalcification of the bone ends with further invasion of the clot by young undifferentiated granulation tissue, which undergoes a metaplasia. About 10 days after the injury a gradual reversal of the pH to the alkaline side occurs. Coincidentally with this change in pH, calcium is deposited and granu-



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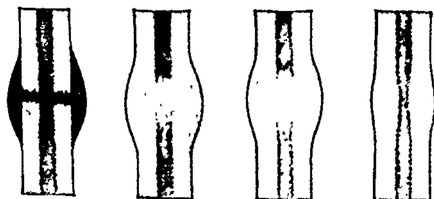


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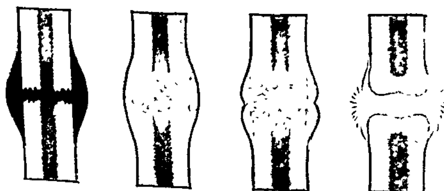


FIGURE 101. Healing of an imperfectly immobilized fracture. Shearing and rotation strains create a plane of cleavage. Continuity is interrupted and fibrous tissue is laid down parallel with the fractured surfaces. (From Watson-Jones, R., *Fractures and Joint Injuries,* Vol. I, 4th ed. Baltimore: Williams & Wilkins, 1952. Courtesy of E. & S. Livingstone, Limited.)

lation tissue is transformed into callus. Apparently the calcium, in the major part, is derived from the local decalcification of the bone ends. The subperiosteal proliferation of osteoblasts as well as the mineral in the bone matrix plays an important role in the transformation of the granulation tissue into callus.

In those fractures in which the fragments are slightly separated or not completely immobilized (Fig. 101), the ingrowing connective tissue cells undergo a metaplasia and become what Moore and Key (1928) call "chondroid tissue" rather than true hyaline cartilage. It is essentially movement that produces this type of cartilage. Delayed or nonunion may evolve from this. This chondroid tissue can become progressively more dense, however, with calcium deposited in the cartilaginous-like tissue.

From the spindle-shaped cells or "resting osteoblasts" lining the inner (cambium) layer of the periosteum evolve the subperiosteal proliferation of the osteoblasts (osteoid tissue). Also, to a lesser degree, there is osteoblastic activity from the endosteum. These osteoblasts normally invade the fibrocartilaginous mass between the bone ends and form a spindle of callus, cementing the bone ends together. The callus is molded continuously by resorption of the recently formed bone, and restoration of the normal bone pattern follows.

Permanent cortical bone. The callus gradually undergoes some shrinkage through absorption. Formation of true bone from the osteogenic cells or osteoblasts has begun under the stripped-up periosteum in the vicinity of the bone ends; this usually begins the second week and gradually extends to invade and replace the coarse cancellous tissue. New bone formed in this way is not spongy bone but has the characteristics of compact cortical bone. When the fracture occurs in childhood, dense bone scarring and thickening will be visible for a long time but gradually a normal marrow cavity with its cortical bone, Haversian canals and its surrounding periosteum results. In the adult after bone healing there is some residual scarring and the site of fracture can be usually easily identified for many years after the fracture occurred.

Repair of Cancellous Bone. In the repair of cortical bone the subperiosteal osteoblasts play the major role, whereas in the repair of cancellous bone the osteogenesis occurs from the endosteum of the entire surface of the trabeculae of cancellous tissue. This is due to the fact that the many metaphyseal vessels and the terminal loops of the nutrient artery provide a very rich vascular supply. These fractures

heal more rapidly than cortical fractures and also heal without the production of callus about their periphery. The surfaces of the fractured cancellous bone heal with the minimum amount of scar tissue. Restoration of the normal cancellous pattern follows.

Treatment of Simple Fractures

First-aid Care. All fresh fractures must be regarded as emergency cases. Injudicious haste and unnecessary roughness in handling the fracture should be condemned, as these procedures produce additional damage to the soft structures and may cause increased displacement of the fragments. Fractures in various portions of the body require individual care, but the general principle for emergency treatment should be to "splint them where they lie."

Sometimes treatment of the fracture is of secondary importance to that of the shock, but a true estimate of shock often cannot be determined at the site of the accident. It is safer in all fracture cases to splint the fracture gently and quickly at the site of the accident and cover the patient with blankets to keep him warm while he is being transported to the hospital. The Thomas knee splint and the Murray-Jones arm splints, as well as the usual first-aid kits containing chemotherapeutic drugs, should be readily available in ambulances. Roentgenograms should be taken as soon as feasible after the patient's arrival at the hospital. While the film is being developed, a careful physical examination should be made.

Closed Reduction. The form of treatment for the individual patient will vary. In general, (1) *early reduction* with the minimum amount of trauma, (2) *adequate fixation* to give the optimum degree of immobilization and (3) *early restoration of function* to the part should be the aim in each case.

In all patients in whom manipulation is required, some form of anesthesia is necessary. If a general anesthetic is used, ether is the safest; in the hands of a skilled anesthetist, the decision can be left to him. The use of a local anesthetic is valuable in selected cases, in the aged patient or when general anesthesia is contraindicated. A 1 to 2 per cent solution of procaine hydrochloride injected into the hematoma around the fracture relieves pain and muscle spasm, allowing, in many instances, as satisfactory a reduction as would be permitted under general anesthesia.

Delay in reduction usually converts an easy reduction into a difficult one. The fluoroscope is a valuable aid in the reduction of many frac-

tures, especially in the smaller joints of the extremities, but there is a danger from overexposure of radiation to the operator who treats many fractures. A postreduction roentgen examination should also always be made, for it is of value in showing the position of the reduced fracture, as well as being a permanent record that might be useful later in any legal complication.

The splints must extend beyond the joints proximal and distal to the fracture, but should not be long enough to impede the motion of any other joint which can be safely moved. In closed reduction of any fracture in which traction and suspension are required, the overhead Balkan frame may be used to suspend the splint. The Australian or Russell traction depends for its force upon its double-pulley system and finds its most practical use in certain fractures of the shaft of the femur. Traction can also be obtained by pulling on the skin with moleskin or adhesive plaster (Buck's extension) or by the so-called skeletal method with pins, tongs or wires inserted in or through the bone, with the limb supported on the Braun frame. The amount of weight should be enough to reduce the fracture, and should be made heavy the first few days and then decreased. It must not produce distraction of the bone ends. The fixed-pin traction of Roger Anderson, in which two Steinmann pins are driven through the proximal fragment and two through the distal portion, the pins being held by external fixation or plaster of Paris following reduction by the Anderson machine, is at times useful. Its great value lies in the fact that it allows motion of the adjacent joints and permits the patient to be up on crutches in a few days. This method is not without certain technical difficulties, even though it is based upon the sound principle of immobilization of the fracture with early mobilization of the adjacent joints, thereby hastening the restoration of normal function. The Roger Anderson, Haines and Stader splints of external skeletal fixation all have the same principle, and are desirable in selected cases, but only in the specialist's hands.

Intramedullary Fixation (Küntscher Nailing). The intramedullary nail or rod fixation for fractures was used extensively by Küntscher originally and others in World War II and is having increasing popularity in civilian practice (Kirschner, 1949; Street, 1950). Küntscher rods have been used in the treatment of fractures in all the long bones, but the best results have been obtained in fractures of the upper and middle third of the femoral shaft (Fig. 102; see also Chapter 10. The most satisfactory end results have been in the transverse or oblique



FIGURE 102. Fracture of upper third of femoral shaft. *Left*, before Kuntscher nailing, *right*, after Kuntscher nailing

types of simple fractures and not in the badly comminuted or compound fracture

Blind intramedullary nailing is not recommended and its use in children is contraindicated The open procedure for the femur is as follows

The posterolateral femoral approach is used and the nail must not be too long, too short, too big or too small, remembering that the width of the medullary cavity differs in different bones, and that there are varying femoral diameters in different individuals An adequate set of instruments must be available, consisting of reamers, an extractor, a guide wire and an assorted number, size and length of Küntscher nails. After the bone ends are exposed at the fracture site, the guide wire is inserted upward into the proximal fragment until the tip of the greater trochanter is penetrated A small opening is reamed out at this point and the Küntscher nail driven down the medullary cavity along the

guide wire until the site of fracture is reached. The fracture is then reduced and the nail driven further into the medullary cavity of the distal fragment until it is well engaged in the metaphyseal region, taking care to have the nail slightly embedded in the cortex at its distal point to prevent rotation.

This method of fracture fixation has certain dangers and complications such as the possibility of the nail bending, getting caught in a too narrow medullary cavity or wandering up or down from its original position. The danger of infection cannot be entirely eliminated, although under aseptic precautions this is unlikely. When properly applied the nail has the great advantage of accurate reduction, contact compression force and immobilization as well as early ambulation. With intermittent pressure forces acting at the fracture site earlier bone healing is stimulated and restoration of joint function is hastened.

Plate Fixation. Open reduction may be necessary because of hemorrhage at the site of fracture, interposition of soft tissue between the fragments, or whenever the fracture line or lines may preclude satisfactory closed reduction and retention. Whenever the fracture is of such a type that satisfactory position cannot be maintained by closed methods of treatment, open operation should be considered. In well-organized surgical centers many more fractures can be safely treated by open reduction, thus securing earlier restoration of function, but the dangers in performing a major operation in the case of every fracture are obvious.

The great majority of fractures, however, can be treated successfully without resorting to open reduction; therefore, it should be reserved for those cases in which closed reduction and suspension or fixed-pin traction cannot be expected to yield a satisfactory degree of reduction and fixation. If open reduction is done, a vitallium plate or similar inert alloy, employing not less than four screws which must not be too long and must penetrate both cortices of the bone fragments, may be used. Various varieties of screws, nails, pins and wire are used to give immobilization to the fragments, but *as a rule the minimum amount of hardware should be used;* in any given case the same type of metal must be used throughout.

In all internal fixation of fractures the great danger is an operative infection that may result in osteomyelitis, so that very careful and meticulous attention to surgical details is necessary. After internal fixation one may apply, for a limited time, (1) external immobilization by means of temporary plaster of Paris casings or splints, or (2)

immediate mobilization of the part by suspending it in balanced traction.

Complications. *Posttraumatic acute bone atrophy* (*Sudeck's atrophy*). This is a type of osteoporosis which is sometimes overlooked. It was described by Sudeck (1900) as a clinical entity, and may be responsible for the severe disability occasionally seen following the reduction and healing of a fracture after the bones are firmly united. It may even follow a minor trauma to a joint, such as a sprain.



FIGURE 103. Sudeck's atrophy of the left foot. Compare this with bone detail of the right foot.

This must not be confused with the normal bone atrophy which follows immobilization, for with resumption of activity in these cases the mineral salts become redeposited in the atrophic bones, giving rise to normal bone repair. In Sudeck's atrophy, however, the pain is out of all proportion to the appearance (Fig. 103), and the bones undergo an extensive degree of atrophy which is unrelieved by proper immobilization. Injuries to the wrist and ankle more frequently give rise to this entity than do injuries at other sites. The region becomes swollen, tender and discolored, and skin shiny and tense. Physical therapy

alone is ineffective in relieving the condition. The disorder may be neurogenic, possibly owing to a sympathetic disturbance. Sudeck regarded it as a reflex neurotrophic phenomenon.

The patient who refuses to co-operate by moving the fingers or toes following an injury, complains of unexplained pain and has a shiny discolored skin should be watched with care. Active exercises must be insisted upon constantly. Once the case has passed into its chronic stage, recovery of function is very difficult to obtain. When the affection is in the lower extremity, a bivalvular, snug-fitting plaster casing with walking iron, arranged to permit minimal weight bearing, should be applied; this can be removed daily to allow active exercises. This active use combined with physical therapy is at times very effective.

Periarterial sympathectomies are valuable, but only if done in the initial stage of this condition (Moore and Key, 1928); they should be preceded by a trial of sympathetic block.

Traumatic arthritis. This term should be reserved for joint lesions secondary to acute trauma in which a late secondary traumatic osteoarthritis develops. The pathologic picture of a degenerative arthritis may result from fractures extending into a joint, from intra-articular soft tissue lesions such as semilunar cartilage derangement, from a traumatic synovitis or hemarthrosis, from the introduction of a foreign body into a joint or from any condition causing an incongruity of articulating joint surfaces.

Traumatic joint disease is usually monarticular, thereby differing from the generalized degenerative arthritis found in the elderly. Roentgenograms present the characteristic picture of a degenerative arthritis, however, with narrowing of the joint space and formation of bony spurs about the articular margins.

The symptoms of pain, aggravated by movement, and limitation of joint motion are constant. If a weight-bearing joint is affected these symptoms are aggravated.

Treatment should consist of rest, protection of the part by splints or braces and physical therapy. These measures will give some relief. Occasionally operative measures are indicated.

Treatment of Compound Fractures

First-aid Care. Proper emergency treatment for hemorrhage at the scene of the accident is extremely important. It is necessary in transportation to maintain length and position with fixed traction to lessen the danger of infection, and also to prevent undue trauma at the site

of the compound fracture. All the steps in the treatment of compound fractures should become routine procedures, for a waste of time in the immediate care provides the best medium for aerobic and anaerobic organisms to develop.

The patient should be carried quickly to the hospital and if shock is present, transfusion of whole blood, plasma or serum must be given, as well as sedation. As soon as possible the prophylactic dose of tetanus-gas gangrene antitoxin should be given. Prior to its administration, it must be determined whether or not the patient is sensitive to horse serum, and procedures for desensitization undertaken if indicated. External heat is applied and, if bleeding is severe, hemostats are used and a pressure bandage is placed about the limb. A sterile dressing is placed over the wound which is not disturbed until the patient is treated in the operating room. Roentgenograms should be obtained as soon as possible.

Wound Débridement. After the above first-aid treatment has been given, and as soon as the general condition permits it, the patient is moved to the operating room. The previously applied sterile dressing is removed, the surrounding skin is shaved and gently but thoroughly cleansed with soap, water and ether, and if the compound opening is buttonhole in size, it is enlarged. Whenever there is a gaping, lacerated wound, a sharp scalpel is used to cut away the rim of the wound edge; this is followed by a careful débridement of the devitalized skin, fascia, muscle and bone, but only the completely detached bone fragments should be discarded. This must be done gently, meticulously and rapidly, saving as far as possible any partially detached bone fragments.

Contaminated tissue removed in the débridement should be sent to the laboratory for culture for both aerobic and anaerobic organisms. This may disclose much valuable information and allow early adequate treatment for developing gas gangrene or tetanus. Treatment for these conditions should be instituted within the first 48 hours postoperatively.

No antiseptic is used in the wound, for any liquid strong enough to kill bacteria is powerful enough to harm the normal tissue cells. Adequate exposure and thorough mechanical cleansing must be accomplished, using normal saline for 20 minutes by the clock, washing out the hematoma pockets and extravasated blood clots from the depths of the wound outward by means of a soft catheter, care must be taken not to open up channels along the muscle sheaths, which may become passageways in spreading infection. Any bleeding vessels must be tied

off, using as few ligatures as possible. Bleeding from the smaller vessels can be controlled by the application of hemostats for several minutes.

Fixation. After the soft tissues have been adequately treated, the broken bones are placed in the best possible alignment. If they can be locked in position by notching, this method is recommended. In oblique fractures, however, it becomes necessary sometimes to use other types of fixation such as screws or pins; plate fixation is rarely required. If fixation can be obtained by inserting Kirschner wires or Steinmann pins through the bone away from the compound area this is desirable; it is never desirable to insert screws, pins or plates in the wound beyond an 8 hour interval after the accident.

The Lane technic is employed. The surgeon's fingers are carefully kept out of the wound and bone forceps used to hold the fragments. The essential factors in the treatment of these fractures is to obtain *early rigid fixation and a surgically clean wound as soon as possible* after the accident. Local treatment is combined with the systemic use of chemotherapy, penicillin being the drug preferred; 200,000 to 300,000 units of penicillin are given intramuscularly at 4 hour intervals for the first 48 hours followed by tapering-off dosages. In the "penicillin-fast" case other antibiotics should be used.

Finally, the decision must be made regarding closure of the wound. Whether it should be closed tightly, loosely or left wide open must be dependent upon the time interval that has elapsed between the accident and the operation, as well as upon the degree of wound laceration and contamination present. If the wound can be cleansed within 8 hours after the accident, primary closure of the skin with the sutures loosely tied is advocated. If it is felt there is a possibility the gross contamination received at the time of the accident precludes closure, the wound should be loosely packed with petrolatum gauze and secondarily closed, the part being adequately *immobilized by a plaster cast.* When the patient leaves the operating room, the injured part must be suspended and protected by sandbags to prevent it from rolling from side to side. This will also lessen some of the postoperative muscle spasm.

Although chemotherapy will inhibit infection in wounds, adequate preliminary surgery is the prime requisite and should never be inadequately performed. After the 8 hour interval it is best that the wound be routinely left open, allowing it to heal by secondary intention, and a well-fitting plaster casing applied. Early treatment of compound frac-

tures should follow three general principles: (1) care for the general condition of the patient, (2) the best alignment and best function possible, and (3) prevention or control of infection.

Aftertreatment. The aftertreatment of compound fractures necessitates careful watching of the patient for the first week or ten days for constitutional symptoms, and if elevation of temperature persists the wound should be inspected and dressed. If one of the drugs of the sulfonamide groups, penicillin or streptomycin is given daily for the first few weeks after the operation, watch should always be kept for possible signs of drug toxicity, such as hematuria, leukopenia, deafness, occasional drug fever or jaundice, and the drug discontinued at the earliest evidence of any such complication. Frequent dressing of the wound should be avoided and immobilization should be continued until there is evidence of bony union. If immobilization is satisfactory and the course uneventful, inspection of the wound may be delayed from 4 to 6 weeks, after which period another plaster can be applied and the process repeated until bony union or the need for further secondary surgery is evident.

Complications. *Gas gangrene.* Gas gangrene, or infection from *Clostridium welchii*, must always be feared if there has been extensive laceration of the tissues, or if the wound has been grossly contaminated by manure. If the patient at any time presents a high temperature, rapid pulse, or if crepitation is felt in the surrounding soft tissues or air bubbles are noted in the roentgenogram, culture for *Clostridium welchii* should be made at once. Usually a characteristic sickening, sweetish odor is associated with gas gangrene When the infection is present, polyvalent antitoxin in large quantities of 10,000 units or more should be given intramuscularly and deep radiation therapy instituted immediately. Radiation therapy probably has no effect upon the progress of the fulminating type of gas gangrene, but appears to bring some localization of the process when given early and is of definite value if the patient has survived for 48 hours or longer. The use of zinc peroxide paste in the débrided wounds has been reported of value (Caldwell, 1941). Liberal incision into the soft parts with the excision of all dead muscle, leaving the wound wide open, should be performed as soon as possible; *no form of internal fixation should ever be used in suspected cases of gas gangrene.* Large doses of the appropriate antibiotic must be given early.

Whenever amputation seems necessary, this measure must be decided upon early, before there is a marked extension of the gas into

the surrounding tissues, for then it may be too late for amputation to be of benefit.

Tetanus. Another anaerobe that should be watched for is the tetanus bacillus, *Clostridium tetani.* The early symptoms of trismus (lockjaw), followed by spasticity of the back and neck muscles and later generalized muscular contractions, are characteristic of tetanus. The mortality is high, being 75 to 90 per cent in the acute cases; the tetanus that appears a few days after the injury offers the gravest prognosis. If tetanus is manifest, the wound must be opened widely and irrigated with hydrogen peroxide. The patient must be kept quiet by sedation and placed in a dark room. Serum therapy may be used; 25,000 units of tetanus antitoxin intraspinally and 50,000 units intravenously or intramuscularly are given each day for three successive days. The danger of tetanus developing must be borne in mind whenever reoperation upon a compound fracture becomes necessary, particularly if less than 6 months has elapsed since the fracture was sustained.

Delayed union or nonunion. Aside from gas gangrene and tetanus, it must be remembered that ordinarily bony union is much slower in the compound than in the simple fracture. Every effort must be made to avoid dis-traction of the fragments at the time of plaster application, for this causes delayed union or nonunion. If the roentgenogram taken through the plaster casing shows dis-traction, this can be corrected by removing a small cuff of plaster circumferentially at the level of the fracture, approximating the cut edges, and then rewrapping the limb without disturbing the underlying dressing.

Delayed Union and Nonunion

Delayed union means that bony consolidation at the site of a fracture has been slower than normal. Nonunion indicates a pseudarthrosis or false joint is present and that bony union cannot be expected through further immobilization. Many times simply *complete immobilization* (Fig. 104) of the fragments over a longer period of time may be all that is necessary to convert a delayed union into a firm bony union, thereby avoiding the conversion of a delayed union into a nonunion.

Causes of Nonunion. (1) *Improper reduction* of the fracture results if the bone ends are not in contact. They may be separated because *soft tissue is interposed* between the ends of the broken bone, or simple *dis-traction* may have been produced by application of too much traction during reduction. (2) *Certain sites* in the body are well known

for their slowness in fracture healing, such as the neck of the femur, the carpal scaphoid and the lower third of the tibia. The fundamental cause for poor results may not always be attributable to poor reduction, but may be on a circulatory basis. (3) *Inadequate nutrition* is an important factor in nonunion. Adequate blood supply is one essential to bone healing, and when the muscles and periosteum with their vessels



FIGURE 104 Nonunion of the scaphoid in a 15-year-old boy. *Left*, effect of conservative treatment by plaster immobilization for 17 months.

have been torn and damaged this may give rise to a local *diminished blood supply*, thereby causing a delay in healing. Therefore, while anatomic reduction is desirable in all types of fractures, it is particularly necessary in the three above-named fractures. (4) *Frequent movement* at the site of fracture retards bone healing by tearing the new tissue framework, and if continued this may cause a pseudarthrosis at the bone ends. It is a dictum in fracture treatment that immobilization of the joint above and below the site of fracture must be accomplished whenever any type of encasing fixation is employed. (5) In severely *comminuted fractures* the fractured bones produce an extensive amount of callus, but bony consolidation is slow and delayed union is not unusual (6) *Age* is an important factor in the repair of tissues; bony union in older persons proceeds much more slowly than in younger individuals. (7) *Infection* is one of the causes of delay or nonunion in fractures. It causes autolysis of the blood clot, and because of the autolytic action of the leukocytes, prevents the formation of pre-callus tissue. (8) With an actual *loss of bony tissue,* such as in gunshot wounds, a delay in union and in some instances a frank nonunion develops.

(9) *Repeated manipulations should never be done*, and if the degree of healing is to be tested clinically, it should be done gently. Much damage can be done by rough handling in an effort to determine a point of motion at the site of fracture. (10) *Other secondary factors causing* delayed or nonunion occasionally cited are endocrine disturbances, vitamin deficiencies, changes in the blood concentration and the presence of synovial fluid in the tissues which may occur in fractures extending into joints.

Careful study of a good roentgenogram, or a consecutive series of roentgenograms, is the best method of determining the course of bone healing. Roentgenograms in cases with bony union show a continuation of the bony *trabeculae across the line of the fracture*, whereas in nonunion or delayed union the edges of the fracture are smooth with an obvious lack of callus thrown out about the fracture site. Syphilis is not considered to be a cause of nonunion.

Treatment. Cases of delayed union can be converted into nonunion by injudicious and hasty decision to subject the bone to excessive stress and strain before bony trabeculae crossing the site of fracture are visible in the roentgenogram. If immobilization is discontinued too early, an increasing amount of movement and pseudarthrosis develops, so that, in the treatment of fractures, union cannot be estimated by the calendar but must be evaluated by the individual problem presented. As has been mentioned, at certain sites in the body it is notoriously difficult to obtain bony union; also, there are individual variations in the rate of callus production. Before advising normal activity of the part, it is better to err on the side of conservatism by further immobilization in plaster rather than to gamble too much on a questionable roentgenogram.

Administration of large doses of calcium gluconate in cases of delayed or ununited fractures is of very doubtful benefit. It has been tried repeatedly, but there is no clear-cut evidence that it has any distinct benefit. Thyroid extract by mouth has been reported (Ravdin, 1947) of some benefit, particularly in the delayed *fracture during the* menopausal period of women. Hypoproteinemia, if present, should be corrected, as it seems to be a deterring factor in all tissue repair. These conservative measures have their field of usefulness in the delayed type of fractures, but if frank nonunion has developed conservatism is a waste of time and an open operation is necessary. In the compound fracture, the method of treatment must be selected after knowing whether active infection is or is not present at the site of the nonunion.

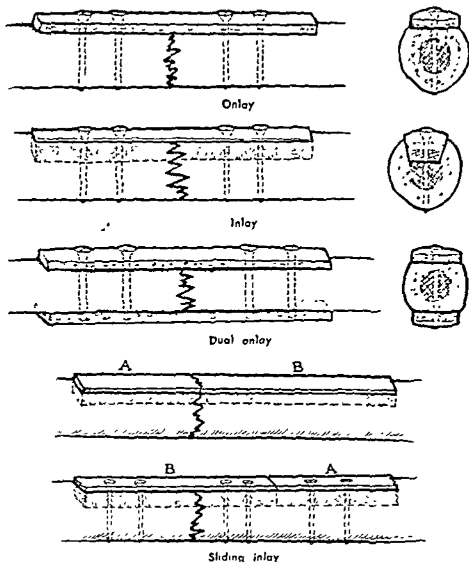


FIGURE 105. Methods for treating delayed union and nonunion.

Operation for nonunion without evidence of local infection. The drilling method consists simply of multiple drill holes made with Kirschner wire or drill; fifteen or twenty holes are made obliquely through the lines of fracture. This is one of the simplest operative procedures to assure some increase in the local blood supply, it may prevent a delayed union from becoming a nonunion

The usual type of open operation for nonunion will consist, however, of removal of interposed soft parts, freshening up of the bone ends and close apposition of the fractured surfaces. A bone graft of the inlay, onlay or sliding type is used to insure further fixation; the massive onlay, held in position by bone pegs or screws, is the most successful. Occasionally some form of step-cut operation (Fig. 105) on the bone,

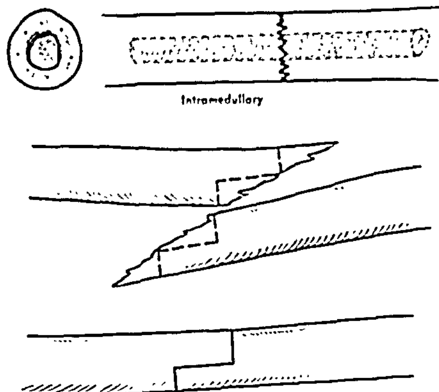


FIGURE 105 (*Continued*). Methods for treating delayed union and nonunion.

which permits the bone ends to be freshened and the length of the bone to be slightly shortened by the "Z" type of osteotomy, may help to hold the fragments in position while transfixation screws are used.

Operation for nonunion with evidence of local infection. With infected fractures the bone ends may be sclerotic and the intervening scar tissue may appear avascular. If the infection is more active, as evidenced by sequestra and involcrum formation, the case must be treated first as one of chronic osteomyelitis, the dead bone being removed and then the adjacent bony tissue saucerized so that wound closure may occur by secondary intention. The problem of how long one should wait after active bone infection before attempting a bone-grafting operation is still unsettled; for in these cases some danger of recurring infection always follows any open surgery. Clinically, there must be complete absence of any infection as evidenced by local heat, sensitiveness, swelling and redness. Sometimes a preliminary manipulation is of value to see if this mild irritation will light up the infection. After the surgeon has convinced himself that the proper time for open surgery has arrived, he may then plan upon a bone-graft operation. As a rule *at least* 6 months should elapse between any evidence of local

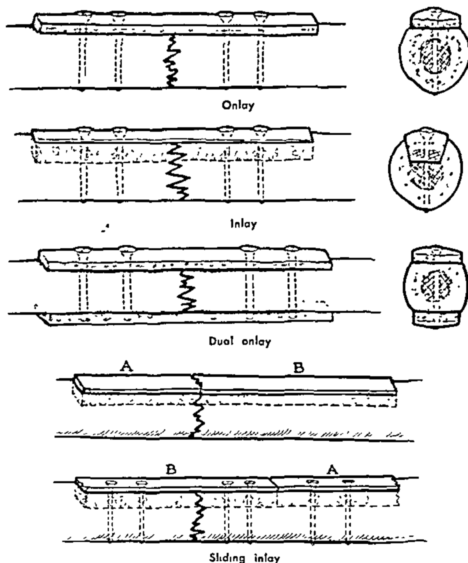


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deformity constitute the clinical picture in the traumatic type and often the articular surfaces can be felt to be in an abnormal position.

Traumatic dislocations comprise a large percentage and are produced by sudden external violence or by muscle action. The shoulder and the fingers are most frequently involved.

Individual joint dislocations are taken up in the regional chapters.

Pathologic dislocations are produced by disease in or adjacent to the joint; this type of dislocation is produced by the gradual pull of the muscles or by gravity, or both, the hip being the joint in which this type of dislocation occurs most frequently.

Congenital dislocations occur during uterine life, either because of an underlying malformation or defective development of the joint structures or because of malposition *in utero*. Congenital dislocation of the hip is the most frequent and is discussed in Chapter 9.

Treatment. Early reduction should be attempted and in a few regions this can be easily accomplished. However, the attempted closed treatment of old traumatic dislocations possesses the added difficulty of dense fibrous tissue formation, and requires so much trauma to effect reduction that it is doubtful whether it should ever be attempted. Open reduction in these old unreduced cases is the method of choice, and even then reductions are sometimes very difficult, resulting in limited joint function.

Occasionally one finds a dislocation produced by severe injury and complicated by a fracture of one or both bones that enter into the joint. In these cases, unless an early closed anatomic reduction is obtained with reposition of the fracture, open reduction is preferred. Rarely can the old malunited fragment be successfully replaced. As a rule absolute immobilization following open or closed reduction of the uncomplicated dislocation should not be prolonged more than a few weeks, although the joint must be protected for several months against redislocation and in the lower extremity far longer against weight bearing. Baking and massage can safely be started at the end of the first week after closed reduction. The various methods of reduction are discussed under the regions involved.

EPIPHYSEAL FRACTURES

Epiphyseal displacements, epiphyseal slippings or epiphyseal fractures are not uncommon in orthopaedic practice, occurring in the first two decades of life. The most frequently seen are the epiphyseal

activity and a bone-graft operation (Fig. 106). A week or ten days preliminary to operation, administration of daily doses of 200,000 units of penicillin intramuscularly is recommended, followed by a sim-



FIGURE 106 The right forearm shows radial nonunion with prominence of the ulnar head and instability at the wrist Local infection followed repeated efforts to correct the nonunion, but after a long period of waiting, a long fibular graft and the Darrach procedure were used. *Right*, the two-year follow-up shows a good functional result and a stable wrist.

ilar dosage for a few weeks postoperatively. A 48-hour preparation of the skin and strict adherence to the Lane technic should be employed in these cases.

DISLOCATIONS

A dislocation is a complete displacement of the normal relationship of joint surfaces *A subluxation is an incomplete dislocation.*

In dislocation no age is exempt. Pain, swelling, ecchymosis and

deformity constitute the clinical picture in the traumatic type and often the articular surfaces can be felt to be in an abnormal position.

Traumatic dislocations comprise a large percentage and are produced by sudden external violence or by muscle action. The shoulder and the fingers are most frequently involved.

Individual joint dislocations are taken up in the regional chapters.

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slippings of the upper femoral epiphysis, although displacements can occur in other joints, being most frequent at the upper and lower ends of humerus, radius and femur; these are discussed under the regions involved. As a rule, except in the hip, they are associated with severe trauma and may occasionally be complicated by fracture of the adjacent diaphysis. In the hip joint there are traumatic and atraumatic types; the latter is seen especially in the fat Fröhlich type of child, and seems to be definitely related to some glandular dysfunction. In the overweight child, any softening in the metaphyseal area must render the child particularly susceptible to epiphyseal displacement at the hip. This is more fully discussed under Chapter 9. (The Hip Joint).



FIGURE 107. Genu valgum caused by injury to the epiphyseal plate following fracture. Cessation of growth to the lateral femoral condyle with continuance of growth to the medial condyle produced the knock-knee deformity.

Occasionally there is longitudinal epiphyseal fracture which may extend into the longitudinal axis of the diaphysis, giving rise to a true fracture through the epiphysis and into the shaft of the bone; this is most frequent in the lower radial, femoral and tibial epiphysis.

Complications. In any epiphyseal fracture or slipping of an epiphysis as result of injury, or epiphyseal deformity as a result of osteomyelitis involving the epiphyseal area, the danger of disturbance of growth is a very real one. Such a complication must be watched for in any and all epiphyseal injuries and infections of the long bones. It may give rise to distortion of growth and later deformities; even a mild sprain without evidence of epiphyseal displacement is a potential troublemaker. Sprains may give rise to arrested growth, but very rarely to increased growth, while an increase in length of the bone may occasionally be observed following infection in the shaft of a long bone; irregularity or cessation of growth follows when the epiphyseal plate area is involved (Fig. 107).

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3

The Spine and Ribs

The spine forms one of the most important and strongest structures of the body. It not only carries the weight of the trunk, but also protects the spinal cord and its nerve roots from injury. Pathologic changes affect the spinal cord and nerves, vertebral bodies, and the intervertebral and interpedicular spaces as well as individual parts of the neural arch.

APPLIED ANATOMY

The Spine

The vertebral column consists of a series of vertebrae extending from the base of the skull through the sacrum and coccyx. The typical vertebra is composed of a body, a foramen for the spinal cord, two laminae, two pedicles and transverse processes, four articular processes, four intervertebral notches and a spinous process (Fig. 108). In studying a roentgenogram of the spine, it must be remembered that each individual vertebra arises from three primary and five secondary centers; the body develops from one primary center, while the two lateral masses which constitute the arch each form from separate primary centers. The secondary centers appear at the tips of the spinous and transverse processes and in the cartilage on the upper and lower surfaces of the bodies, forming the two annular plates. All unite to form one solid structure. The vertebrae make up a flexible column and vary somewhat in size and shape, being held in position by their bony conformation, strong ligaments and muscles. This column transmits the

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Considered from above downward, the adult column is divided into the following regions: (1) the *cervical* spine, normally consisting of seven vertebrae; (2) the *thoracic* or *dorsal* spine, consisting of twelve vertebrae; (3) the *lumbar* spine, consisting of five vertebrae; and in the pelvic region (4) the sacrum and (5) the coccyx, which before adult life are not fused, consisting of five *sacral* and four *coccygeal* vertebrae. All of these segments, except the coccyx, act as a column to support the trunk, and the vertebrae afford protection to the spinal cord and its nerve roots.

Between the bodies of adjacent vertebrae, except the first and second cervical and those of the sacral and coccyxgeal group, is a laminated intervertebral fibrocartilage or disk, which is firmly adherent to the body above and below and which has a soft pulpy center, the *nucleus pulposus*. It is surrounded by a fibrous wall, the *annulus fibrosus*, which was described in 1555 by Vesalius (Bradford and Spurling, 1945). These disks account for one-fourth to one-third of the total length of the spinal column. They absorb the jars caused by walking and aid greatly in increasing the flexibility of the vertebral column. They are resistant to any disease that involves the bodies of the vertebrae. They are especially resistant to tuberculosis, less so to non-tubercular osteomyelitis. The annulus fibrosus is subject to rupture through injury, especially the disks between the fourth and fifth lumbar vertebrae and between the fifth lumbar and first sacral vertebrae. When protrusion of the extruded nucleus pulposus is posterior, it may produce pain in the back and referred pain in the lower extremities. In later life the disks normally undergo some degenerative changes.

If one looks at the spinal column from the lateral view, it does not form a straight line because there is in the cervical and lumbar regions a convexity forward and in the thoracic and pelvic regions a concavity forward. These individual physiologic curves may be accentuated or almost completely lost under abnormal conditions. From the anteroposterior view the spine is normally straight; thus, a plumb line dropped from the posterior occipital tuberosity should fall directly over the intergluteal fold.

Normally the spine is held upright by groups of muscles which act as guide ropes. Although no single muscle runs posteriorly from the skull to the pelvis, there are groups of long, overlapping muscles called the *erector spinae*. These muscles both maintain the spine in an erect position and counteract the tendency of the body to fall forward. The physiologic antagonists of the erector spinae muscles that extend

weight to the lower extremities, the lumbosacral junction being normally the point of most marked shearing stress and strain. Throughout,

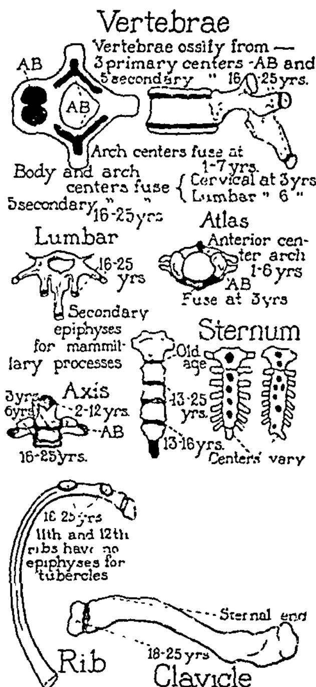


FIGURE 108. Diagram of vertebrae, rib and clavicle showing appearance of epiphyses and age of fusion AB. At birth.

but especially in the lumbosacral area, are found many congenital anomalies; and these often produce an inherent weakness in the low back, rendering this region most susceptible to trauma.

vertebrae, the twelve ribs and their costal cartilages, and the sternum. It contains the lungs, pleura, heart and pericardium. The red marrow of the ribs is rich in osteogenetic power and, therefore, is an easily accessible and satisfactory tissue in bone-grafting operations. The



FIGURE 109. Anatomical model of lumbar vertebrae and sacrum with spinal and sacral nerves *in situ*.

sternum can be used as a bony landmark to identify the vertebral levels: The upper margin of the manubrium is usually on a level with the intervertebral disk between the second and third thoracic vertebrae; the junction of the manubrium and the body (the angle of Louis) corresponds to the disk between the fourth and fifth thoracic vertebrae; the sternal angle is opposite the body of the fifth thoracic vertebra and the second rib; the xiphosternal junction is opposite the disk between the ninth and tenth thoracic vertebrae. Congenital vertebral anomalies frequently accompany congenital anomalies of the ribs, such as an

longitudinally along the back are the abdominal muscles, which produce flexion of the spine, and, closer to the vertebral column, two other powerful muscles, the quadratus lumborum and the psoas, while the neck is flexed by its flexor group.

In addition to the small intervertebral ligaments, there are two important longitudinal ligaments of the spine. (1) The *anterior longitudinal ligament* extends along the front of the bodies of the vertebrae; it widens as it passes downward. It is not attached to the concave centers of the bodies, but leaves a slight space between the ligament and the body, attaching itself to the edges of the vertebrae and the intervertebral disks. (2) The *posterior longitudinal ligament* lies within the spinal canal and is attached closely to the bodies of the vertebrae extending from the axis to the sacrum. Unlike the anterior longitudinal ligament, it narrows as it descends, and instead of having straight edges it is scalloped, widening over the intervertebral disks and narrowing over the bodies. This ligament is generally less powerful than the anterior longitudinal ligament. It may bulge backward under the pressure of the protruding nucleus pulposus, at which time pressure will be produced against the spinal cord or the lateral roots, giving rise to nerve irritation and often sensory changes.

The Spinal Cord

The spinal cord is the great connecting nerve trunk between the brain and the various portions of the body. In adults, it is 17 to 18 inches in length, occupying the upper two-thirds of the spinal canal. It is relatively longer in children as the vertebrae grow more rapidly than the cord, and hence the cord is carried cephalward through the canal. Surrounding the cord are the three membranes: the dura mater, the arachnoid and the pia mater. Thirty-one pairs of spinal nerves originate in the spinal cord and pass outward from the spinal canal through the intervertebral foramina (Fig. 109) to be distributed throughout the body. Owing to growth changes, the respective foramina of the spinal nerves are displaced progressively downward as the termination of the cord is approached, so that finally the roots of the lumbar and sacral nerves extend downward as a mass of almost parallel bundles considerably below the level from which they arise. The terminal nerve roots are given the name of *cauda equina* (horse's tail).

The Thorax (Rib Cage)

The thorax is a dome-shaped bony cage formed by the thoracic

rotary lateral curvature. This latter curve is always accompanied by some rotation of the vertebrae, elevation of one shoulder and prominence of the rib cage and hip on one side.

The range of flexion, extension and lateral bending to the right and left is routinely observed, and the cause of any pain in these directions should be carefully sought (Fig. 110). A plumb line or tape should be dropped from the posterior occipital tuberosity. If there is no body list, this plumb line will coincide with the longitudinal gluteal fold. The leg lengths must be checked as their inequality may distort the picture,

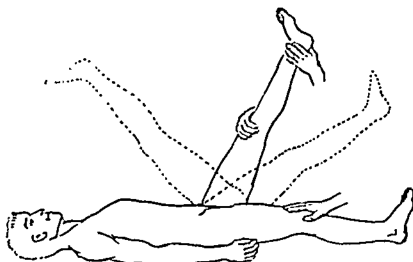


FIGURE 111. Straight-leg-raising test.

and a straight-leg-raising test (Fig. 111) is a routine procedure. The presence or absence of a pelvic tilt should also be observed.

A very slight lateral curvature with convexity to the right in the dorsal region occurs in many individuals. It is so frequently found that this in itself does not suggest any pathologic condition, and has been explained as due most likely to the pressure by the aorta on the vertebral bodies extending from the fifth dorsal to the second or third lumbar vertebra.

Spinal Puncture

When a spinal puncture is indicated, the lumbar region is selected, preferably either just above or below the spine of the fourth lumbar vertebra. The ideal site can be easily determined, for a line passing from the highest point of the crest of one ilium to that of the opposite passes through the lower part of the spine of the fourth lumbar vertebra. As the spinal cord proper extends only to the upper border of the

extra cervical rib, unilateral or bilateral of sixth or seventh cervical vertabra.

EXAMINATION

For the study of the surface markings of the vertebral column, the patient must stand in a good light with his back exposed. The general build and posture of the patient should be noted, as well as any abnormal prominences or depressions of the spinous processes or thorax suggestive of disease or injury. The examiner then runs his fingers down the patient's back in order to feel the contour of the spinous processes and to detect any deviation from the straight line. Also, by palpation, the presence or absence of muscle spasm can be detected. If a lateral curvature is observed, the patient should be asked to bend forward;

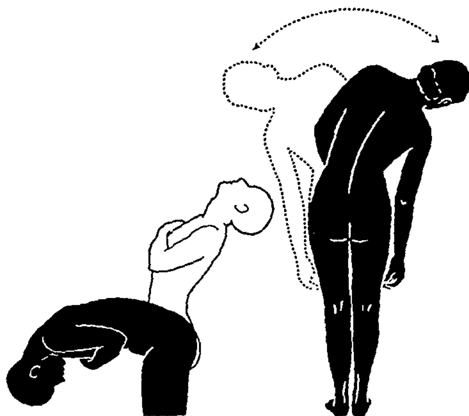


FIGURE 110. Flexibility of the normal spine *Left,* flexion and extension; *right,* lateral deviation.

if this curve disappears on bending forward, it can be considered a *functional curvature* of the spine in contradistinction to those spinal curvatures which do not disappear on flexion — the *structural type* of

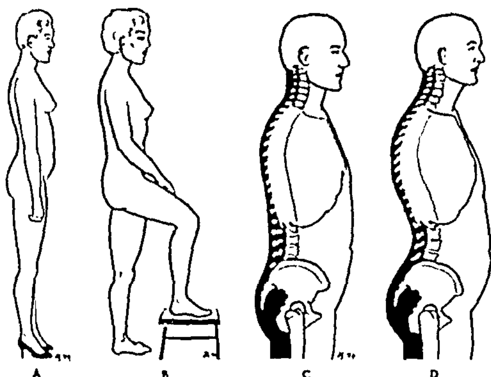


FIGURE 112. Increased lumbosacral strain (A) causes low back pain, which can be relieved (B) by slightly flexing one hip when standing. A flat back (C) corrects the lordotic curve (D).

received and the response to previous treatment may guide the questions and make the probable diagnosis more evident. Sex, occupation, and particularly the decade of life in which low back pain is initiated may help tremendously in the diagnosis.

Remember that low back pain may be the localization of a referred pain or may arise from some pathologic process in the local tissues. The local cause for pain in the back in the young adult (Fig. 112) may so frequently be on a postural basis that this consideration must be foremost in the mind of the examiner if the patient is in the second decade of life.

In the young child with low back pain the cause must painstakingly be sought, for many children have serious causes for low back ache. In each decade of life after this, the probability is greatly increased that the low back pain is the result of a comparatively few common basic causes. These causes, such as the effects of trauma (fracture, strains, etc.), disease (infection, arthritis, etc.) or malignancy superimposed upon a background of mild or severe congenital anomalies, must always be kept in mind.

Inspection. It is obvious that these patients must always be properly disrobed and standing in a good light to study the surface markings of

second lumbar vertebra, the spinal puncture should be made below this point.

Technic of Spinal Puncture. The skin is painted with iodine and anesthetized by 1 to 2 per cent procaine or by freezing with ethyl chloride; aseptic precautions are used throughout. In children the needle is directed at right angles to the body surface and in adults it is inserted obliquely, pointed cephalad.

The spine must be flexed as much as possible, with the patient either sitting or preferably lying on the side, with the chin approaching the knees. A 3 inch needle, with a short bevel and with the stylet remaining within the needle, is inserted in the midline of the back or 1 cm. to the right. Usually the puncture is made between the spinous processes of the fourth and fifth lumbar vertebrae. By directing the needle slightly lateral to the midline, the piercing of the interspinous ligament will be avoided and it will also allow greater ease in entering the intervertebral space. A sense of slight resistance as the needle reaches the ligamentum flavum will be felt. As the needle penetrates the subarachnoid space this resistance disappears. The stylet is then removed and the spinal fluid is collected in a sterile test tube. When desirable, a manometer can be used to register spinal pressure. The spinal tap should reveal color, pressure, cell count, chemical composition and Wassermann. Following the spinal puncture, the patient should remain in the recumbent position for the following 24 hours to avoid any headaches or nausea.

Precautions. If the needle impinges against the vertebrae it is slightly withdrawn and redirected. When it becomes obstructed by a plug of soft tissue the stylet is reinserted and the pathway cleared of obstruction. If the fluid is bloody a venous plexus has usually been punctured, and partly withdrawing and reinserting the needle is necessary.

The Low Back Pain Syndrome

Low back pain still remains a difficult problem and it must always be remembered that the term is a symptom not a diagnosis. The classification listed on page 158 is modified from one originally presented by Ghormley (1944) and is to be kept in mind when examining patients with back ache, with or without pain referred to one or both of the lower extremities.

History. This examination is always time-consuming for the measurements must be recorded at the time they are taken; therefore, the presence of an alert and accurate secretary during the examination is essential. A careful history of onset, the past and present treatment

it can be seen at a glance whether the head is balanced directly over the longitudinal gluteal fold, the fingers should be run up and down the spine along the tips of the spinous processes from the cervical through the lumbosacral region. Minor deviations or curvatures will be palpated while severe curvatures are perfectly evident. The patient is then asked to bend. Even in the young adult, flexing to touch the fingers to the floor may not be possible in a great many seemingly normal individuals; it may be due to short hamstrings, contracted calf muscles or the stiffness of disuse. Such contractures can render the individual more susceptible to the stresses and strains of activity and should be corrected when in the young age group. Hamstring contractures, limitation of full extension at the knees and flexion contractures at the hips should all be observed as they may be, individually or collectively, factors in initiating low back pain.

Following active bending of the trunk in flexion, extension and laterally while standing and sitting, the patient lies on a firm, hard bed and the examiner checks on the straight-leg-raising test (Lasègue's sign) and the measurement of the length and circumference of the limbs. The pelvic crests must be level and the tape line extends from the anterior superior iliac spine to the internal malleolus on both the right and left leg. The circumference of the thigh and leg is also recorded.

Both motor and sensory systems in the lower extremity should be checked by testing the knee and ankle jerks, the areas of sensory diminution and the strength of dorsiflexion of the feet against resistance, especially the big toe.

A rectal examination in the male and a breast examination in the female must be routinely done and sometimes will give a clue toward the diagnosis.

Laboratory. The history and physical examination are often not sufficient and the choice of one or more of the many laboratory studies, always including blood and urine reports and adequate roentgenograms, must be regarded as necessary in any investigation. When an orthopaedist has a close liaison with the roentgenologist, both can learn much.

Therefore, adequate roentgenograms are needed in the care of all cases of backache, but there are certain types of cases in which certain views are absolutely necessary. Roentgenograms are helpful, even if only from a negative standpoint.

While the symptoms of low back pain include a multitude of possi-

the vertebral column. Mistakes in diagnosis sometimes arise if the physician does not acquire and routinely use the clinical skill of keen observation directed toward an individual's build, his limp, or the recognition of normal or abnormal gait in walking. Is there obvious pain or deformity in the low back, increased on activity or recumbency?



FIGURE 113. Sciatic scoliosis. Typical list of body in acute low back pain produced by muscle spasm.

Inspection of the degree and manner of back bending will disclose the amount of limitation and whether it is accompanied by pain and muscle spasm (Fig. 113). Does one or both of the lower erector spinae muscle bundles stand out prominently in the back? Is one hip obviously higher than the other? If so, how much elevation under the shoe is necessary to correct the imbalance?

One must not neglect noticing the feet in walking; whether there is an excessive degree of pronation; whether the heel cords seem unnecessarily tight; or whether a hamstring contracture prevents the smooth, fluid movement that denotes muscle co-ordination.

Palpation. A good deal of information may be obtained from palpation. The patient stands with his back to the examiner, and while

B. Malignant tumors
1. Primary osteogenic sarcoma
2. Metastasis (prostatic and mammary carcinoma, etc.)
3. Myeloma
4. Ewing's tumor and other rare tumors
C. Tumors of the spinal cord, etc.

VII. Neurologic conditions

VIII. Abdominovisceral Pathology, including the Genitourinary Tract

IX. Anxiety Neuroses

In summary, the common causes of low back pain in the period of youth, with its vigor and activity, are frequent strains, dislocations and fractures; in the older age period, diseases and the degenerative changes of arthritis are commonly seen; and lastly, in the senescent years, osteoporosis and the well-established degenerative arthritic processes form the pattern in the majority of patients. However, one must never forget that new growths, either primary or metastatic, and many diverse congenital bony anomalies of the low back may be present singly or collectively to cause low back pain through all periods of life.

POSTURAL DEFORMITIES

The human form is a composite of balanced forces and is the result of slow evolution as the upright position has been assumed (Fig. 114). The shifting of forces in which the accumulated weight of the trunk and upper extremities is concentrated to a narrow base, the sacrum, has given rise to many postural deformities. Man is not yet perfectly adjusted to the upright position, as evidenced by the many functional disturbances associated with the support of the movements of his body weight. Unequal strain on the ligaments and muscles about the joints can develop. Unbalanced posture not only puts a chronic strain on the muscles that must contract against the pull of gravity, but if maintained over a long period of time it may distort the bones themselves and certainly affects unfavorably the circulation to the joints, lungs, abdominal organs and other soft tissues.

The spinal column carries and controls all of the superimposed weight, so that compensatory curves must be developed. A straight segmented column would be unsuited to carry a load such as the thorax. The spine at birth is practically straight, but shortly thereafter the dorsal and sacral curves become evident, and as the gain in muscle

bilities, there are a few common causes and many uncommon ones. The accompanying outline may identify these two types.

LOW BACK PAIN SYNDROME *

OUTLINE

More Common Causes

I. Posture
  - A. Acute strain
  - B. Chronic strain
    1. Lumbosacral or sacroiliac lesions
    2. Tensor fascia spasm

II. Trauma
  - A. *Involving the vertebrae*
    1. Fracture of the body
    2. Fracture of the pedicles
    3. Fracture of the laminae
    4. Fracture of the facets
  - B. Involving joints
    1. Traumatic spondylosis
  - C. Involving disks
    1. Narrowing of disks
    2. Protrusion of nucleus pulposus
    3. Rupture of nucleus pulposus

III. Infection
  - A. Arthritis, infectious (typhoid spine, influenza, etc.)
  - B. Spondylitis deformans or rhizomelic spondylosis
  - C. Fibrositis
  - D. Tuberculosis

IV. Metabolic and senescent conditions
  - A. Hypertrophic changes (may be traumatic)
  - B. Osteoporosis with or without pathologic fracture

V. Congenital anomalies
  - A. Spina bifida
  - B. Sacralization of fifth lumbar vertebra or lumbarization of first sacral vertebra
  - C. Anomalous facets
  - D. Lack of fusion in neural ring (may produce spondylolisthesis)

Less Common Causes

VI. Neoplastic conditions
  - A. Benign tumors
    1. Osteoma and osteochondroma
    2. Giant cell tumor
    3. Hemangioma

* Modified from Ghormley (1944).

In the case of severe posterior curvature of the spine, which develops rapidly in the adolescent and is often accompanied by sensitiveness to pressure on the spinous processes, the roentgenographic examination shows irregularity in the epiphyseal portion of the vertebral bodies.



FIGURE 115. Patient with generally poor posture, including dorsum rotundum.

The intervertebral spaces are narrowed, and the anterior surfaces of the vertebral bodies become wedge-shaped. An indentation in the anterior portion of the bodies may be noted in some spines in young children, and it is believed that round shoulders are prone to develop later in these children.

In the more severe type of case, exercises offer very little in correcting the deformity. Rest in bed and gradual correction of the dorsal kyphosis is advisable. Fusion of the deformed area to avoid recurrence of the deformity may be necessary in selected cases. Braces and shoulder straps have a very small part in the treatment of these patients beyond being of some psychologic value.

power continues, the infant is able to hold its head erect and soon develops the cervical and lumbar curves. The lumbar region assumes normal convexity as the pelvis is tilted downward by the extension of the thighs.

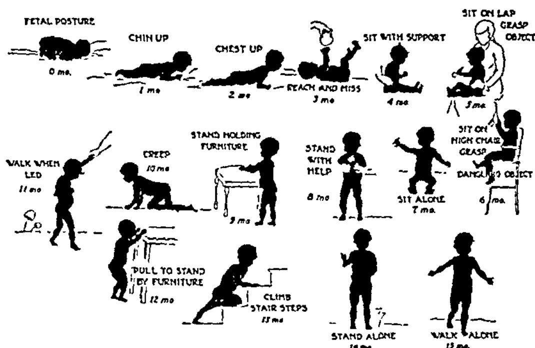


FIGURE 114 Motor development of the child. (Shirley, Mary M. *The First Two Years, Vol. II.* Minneapolis, Minn.: The University of Minnesota Press.)

Postural Kyphosis (Round Shoulders)

Postural kyphosis (round shoulders) is one of the most common deformities occurring during growth, and in childhood may be induced by hereditary characteristics, general muscular weakness, respiratory obstruction, rickets, or even by tight clothing about the chest and shoulders. During adolescence an extreme type of dorsal kyphosis may develop; in this *posterior-dorsal* curvature the deformity is very resistant to correction and may be accompanied by fatigue and by pain in the back and limbs. In the simpler cases of round shoulders which do not present evidences of epiphyseal irritation or show gross abnormality on roentgenograms, attention to a well-balanced posture with exercises to improve the muscle tone is often sufficient to assure correction. Pain on pressure over the spinous processes should be sought in the severe dorsum rotundum cases (Fig. 115); when present, it suggests a diagnosis of *vertebral epiphysitis* (Scheuermann's disease).

II. Acquired scoliosis
   A. Affections of the vertebral bodies
      1. Rickets
      2. Osteomalacia
      3. Neurofibromatosis
      4. Tumors
   B. Affections of the bones and joints of the lower extremity, causing pelvic imbalance
   C. Affections of the soft tissue structures
      1. Anterior poliomyelitis
      2. Cerebral palsy and other central nervous system disorders
      3. Empyema
      4. Scars, especially those seen following thoracoplasty
   D. Idiopathic scoliosis.

A form of lateral deviation of the spine designated as functional or total scoliosis is recognized and has been discussed in the preceding section.

By far the greatest number of cases will fall into the last group, idiopathic scoliosis, in which the cause of the curvature is not known. Scoliosis due to anterior poliomyelitis forms another large group of cases, and this type is discussed elsewhere with the other deformities associated with this disease (Chapter 15). Although various types of body posture and habit have been described as the cause of idiopathic scoliosis, no definite relationship has ever been established.

Idiopathic curvature of the spine and thorax (Fig. 116) is a serious deformity and produces many secondary changes in the heart, lungs, and abdominal viscera. A lateral deviation of the spine is accompanied by a twisting or rotation of the bodies of the vertebrae. This type should be differentiated from the so-called postural scoliosis or functional type which rarely shows definite structural changes, at least not until late in the development of the curve. Rotary lateral curvature may be the result of rickets, infantile paralysis, empyema and other known conditions affecting the body, but a large percentage of cases of scoliosis occurs in adolescent females, and without any known causative factor. A very resistant type of structural scoliosis develops in patients with multiple neurofibromatosis and these cases require early correction and fusion.

As the deformity is practically limited to human beings, one might conclude that the force of gravity in the upright posture plays a very real part in its production. It may be that further study will also show some definite relation to glandular dysfunction. As the vertebral column is a flexible, weight-bearing rod, curved in the lateral plane, it

Lateral Curvature of the Spine

In addition to the anteroposterior deformity of the spine just discussed, another type of postural deformity, lateral curvature of the spine, is frequently encountered in growing children. A simple lateral curvature caused by unbalanced posture differs fundamentally from a severe type of rotary lateral curvature. In the simple curve, rotation of the vertebrae is very slight. In some instances the spine may be bent laterally into one long curve, the so-called *total scoliosis*, or there may be present an ordinary S-shaped or double curve, one portion of which is primary and the other secondary in its origin. Deformity of one part of the spine is usually balanced by deformity in the opposite direction in another region of the spine — the compensatory curve. This is necessary to keep the patient from falling.

The simplest form of acquired lateral curvature is produced by muscle imbalance, as is seen in poliomyelitis. It may be aggravated by inequality in the length of the lower extremities or by improper attitude in sitting and walking, but this type of spinal deformity is not a disease process *per se*. Every effort should first be made to determine and correct this mechanical imbalance. Many of these slight curves will disappear following correction of the inequality in length of the extremities, or after the muscle imbalance has been rectified by massage and muscle training. The aim is to maintain balanced posture in these patients. Development of weakened muscle groups by carefully selected gymnasium and swimming exercises should be stressed. Two simple tests to differentiate between functional and structural types of spinal curvature are to determine by roentgenogram whether there is a fixed vertebral rotation or whether the scoliosis disappears when bending forward from a sitting position. The former indicates a structural scoliosis; the latter a functional curve.

STRUCTURAL SPINAL DEFORMITIES

Scoliosis

It may be stated that any process that affects the normal trunk may produce scoliosis. A convenient classification follows:

1. Congenital scoliosis
   - A. Hemivertebra
   - B. Failure of segmentation of vertebra
   - C. Congenital malformation of the scapula
   - D. Congenital malformation of the thorax

its length, or is curved in one direction in one part and in an opposite direction above or below, or both above and below. Lateral deviation is accompanied by rotation or turning of the vertebral body on a vertical axis.

The degree of distortion of the vertebral body will depend upon its location within the curve. The body at the apex of the curve will present the most severe distortion and those extending away from it, both cephalad and caudad, will present decreasing degrees of deformity.

The apex vertebra is wedge-shaped. This wedging may take place on both the superior and inferior surfaces. As would be expected, the narrowest part of the wedge is found on the concave side of the curvature and since the vertebral body is rotated to the convexity, there is some wedging of the posterior aspect of the body as well as of the lateral portion. In older persons with long-standing scoliosis, lipping between vertebral bodies occurs, progressing in some cases to a synostosis. The vertebral foramen are distorted, the pedicles are shortened on the concave side of the curve and are oblique on the convex side. The articular processes on the concavity are usually enlarged and deepened, while on the convex side they are smaller and higher. Generally, the spinous processes are directed toward the side of the concavity. The intervertebral disks are compressed on the concave side of the curve and are thicker on the convex side.

Changes may also take place in the ligaments and muscles. On the side of the concavity, the longitudinal ligament is usually dense and thick, whereas on the convex side it is thin and dispersed. Various degrees of atrophy and degeneration of the muscles involved may take place. There is shortening on the concave side of the curve. These are recognized, of course, only in the more severe cases but are assumed to take place in the less severe cases as well.

Changes in the thorax are most severe when the dorsal segments are involved. The thorax is displaced toward the convexity of the curve. In the frontal plane, the thorax tends to maintain its normal position so that the spine, as it were, seems to twist within the thorax. This results in distortion of the horizontal diagonal diameters of the thorax. The one from the convexity behind to the concavity in front is lengthened, whereas the opposite one is shortened. Because of the rotation of the vertebrae, the ribs on the convex side of the curve are angled backward (the typical "razor-back deformity"), producing severe cosmetic as well as physiologic changes. The ribs on the concave side are



FIGURE 116. Severe idiopathic scoliosis, showing structural deformity. *Left*, erect; *right*, forward bending.

cannot yield in another plane without a twisting motion; and in this twist the vertebrae turn in one direction, namely, away from the greatest weight mass. As the greatest weight and pressure are on the concave side of the lateral curve, it follows that the bodies must turn toward the convex side. In this way the *primary*, or more fixed curve, and the *secondary*, or more movable curve, develop. Occasionally *triple* curves may be seen, and in all compound curves they alternate to the right and left. Many varieties of compound curves may develop, but the usual type is that in which the convexity is toward the right in the thoracic region and toward the left in the lumbar region. This is the ordinary S-shaped curve in which the high shoulder appears on the convexity side of the thoracic curve and the prominent hip on the opposite side. The vertebrae at the apex of each curve show the greatest change, as they are at times not only severely rotated but their bodies may show severe wedging; this is true to a lesser degree for those more distal to the apex of the curve.

Pathology. It must be recognized that, depending upon the severity of the curvature, all degrees of deformity may be encountered from the mildest to the most severe. The spine is curved to one side in part or in all

curve can be determined and differentiation may be made between the primary and secondary curve.

Diagnosis. Examination should include an estimate of the general trunk alignment and of the development of secondary curves and chest deformity. The curve or curves should be tested for mobility, both actively and passively, as well as for response to traction. Assessment of muscle groups should be made. Measurement of the lower extremities and of the standing and sitting heights is always made.

The deformity is most commonly seen in adolescent girls but may occur in males as well. It may also appear before adolescence. Increase in severity may be steady or intermittent; progress may be rapid or slow and may even stop as a mild curvature. In general, however, the tendency is to grow in progressive severity until cessation of vertebral growth. This is usually at the age of 15 or 16 years in girls and 16 or 17 years in boys.

It is assumed that whatever the etiologic factor may be that causes idiopathic scoliosis it acts over a certain designated number of vertebral segments, producing the lateral curvature. This is designated as the primary curve. Depending upon the level of this primary curvature, the trunk will attempt to maintain itself centered over the pelvis. This results in secondary curves above or below the primary curvature, or both above and below the primary curvature. Early in this process, the secondary or compensatory curves are completely correctable by voluntary muscle action. Later they may develop secondary fixed characteristics that require external force for correction. In some cases etiologic factors seem to affect adjacent segments of the spine, giving rise to a double primary type of curvature. In these cases the body will still attempt to maintain its balance. The etiologic factors may operate in an area of the spine that does not allow for proper compensation above or below the levels of primary deformity and severe trunk imbalance results.

The most common type of curve seen in idiopathic scoliosis occurs in the dorsal level of the spine with convexity to the right. In addition to this type of curvature, primary dorsal, primary cervical dorsal, primary dorsolumbar and primary lumbar curves are recognized.

The diagnosis of rotary lateral curvature should be evident upon careful inspection of the back, but roentgenograms will give more detailed data upon which the treatment best suited to the individual case may be based. In making a diagnosis of rotary lateral curvature,

flattened in their angles with some increase in the curvature in the front of the thorax forming a prominence at the side of the sternum. The ribs on the concave side are closer together and more horizontal in their course. The scapula on the side of the convexity is elevated and will be more prominent, depending upon the degree of rotation.

In severe types of idiopathic scoliosis ("razor-back deformity") function of the internal organs is impaired. The most serious impairment is that of pulmonary function, although in curvatures confined to the lumbar region, pulmonary function is not affected. In thoracic curvatures of 45 degrees or greater, not only is the vital capacity of the lungs greatly diminished, but the heart and blood vessels are displaced, the pulse rate becomes rapid, and other evidences of interference with the vital functions are noted. No exact measurement of the impairment of the heart and great vessels has been made, although it is known that hypertrophy and dilatation of the cavity of the heart are frequent. When the curve affects the lower part of the spine, the pelvis and spine may be distorted, producing abnormal pressure and strain upon the abdominal organs.

The mobility of the spine is lessened by these structural deformities, and the muscles on the concave and convex side of the curve, both intrinsic and extrinsic, are affected by the lateral curvature and rotation. The rib cage follows and partakes of these deformities. At the apex of the convexity of the curve the rib angles project and the lateral convexity of the chest is diminished, but on the opposite side the back is broadened and flattened.

Clinical Picture. In the majority of patients the prominent shoulder or high hip may be the first indication of spinal deformity. Rarely does the patient complain of any pain in the beginning. As the deformity increases, however, the discomfort becomes more intense and pain may develop in the back and along the ribs or down the limbs. There may be other secondary symptoms such as shortness of breath and gastrointestinal disturbances, but rarely are these symptoms found until the bony deformity becomes quite severe.

The rate of progression of the curves varies considerably and it is very important that this rate be determined. At present, the most reliable method is by a careful comparison of identically focused roentgen films, taken at intervals of a few months, with the patient in both standing and supine positions, as well as in lateral bending position to either side. From these the rate of curve growth and the degree of the

factor of gravity and *put the patient in bed,* applying then some form of active corrective force. This will often permit the primary curve to be corrected.

At times a decision must be made as to whether a prolonged period of treatment will be indicated to give a certain minimal functional improvement. For example, a 20-degree curvature in an 18-year-old boy can be expected to progress no further and this degree of curvature should give him no disability in later life. Any forceful correction of this curvature would not be indicated. Appearing in an 11-year-old child, however, this same degree of curvature would demand close, careful observation, with the assumption that it is likely to grow worse in the years of active spinal growth ahead and need forceful correction.

The amount of deformity present in a lateral deformity of the spine can be expressed numerically. This numerical expression describes the amount of lateral deformity present in a particular curve. It does not express the deformity present due to rotation; it may not give an accurate description of the deformity in relation to the body as a whole. Deformity to the body as a whole depends not only on the severity of a single curve, but on other features, such as the level of this curve in the spine and the amount of compensation present or available above or below the curve. In general, one of two methods are used for the measurement of a curve. In both methods measurements are made from roentgenograms; these should be designated as standing, lying, bending.

In the first method the end vertebrae of the curve to be measured are located. These vertebrae are the last vertebrae to tilt cephalocaudal toward the concavity of the curve, or they may sometimes represent neutral vertebrae between adjoining curves. A line is constructed corresponding to the plane of the cephalad surface of the body of the top end vertebra. A line is also constructed corresponding to the plane of the caudal surface of the body of the bottom end vertebra. Perpendiculars are then erected to these lines. The angle at which the two perpendiculars meet denotes the degree of deformity present in the curve (Fig. 117).

In the second method the end vertebrae are designated as in first method. The centers of the bodies of these vertebrae are marked with a dot. Similarly, the center of the body of the apex vertebra is marked with a dot. This vertebra may be distinguished by one, or more than one, of three characteristics: (1) It is the vertebra of greatest lateral

one should try to determine the basic etiologic factor or factors. It must be remembered that this type of scoliosis is not a primary disease of the spine, but a combination of unbalanced mechanical forces existing over a long period of time, plus some as yet unknown factor.

Prognosis. In considering the prognosis of this very serious deformity one must *first be concerned with the rate of curve development.* This change is apt to be most active in the growing period of the individual and usually becomes stationary when the period of bone growth is completed. This means that in a boy of 17 and a girl of 16 it is unlikely that the deformity will increase. Abbott and his co-workers (1947) have suggested using the time of fusion of the iliac crests as a criterion for the completion of bone growth. Therefore, scoliosis in a young child presents a far more serious outlook than that developing in an older patient because of this probability of a rapid increase in deformity. Unfortunately one cannot always have the opportunity of seeing the patient early enough to initiate any worthwhile preventive treatment. These patients are usually brought to the physician after the deformity has become well developed and often require more vigorous measures than exercises or back supports.

Treatment. It is apparent from the preceding discussion that treatment of lateral curvature of the spine is a complex problem. The age of the patient, the severity of the curvature, the level of the curvature, the degree of rotation, the amount of compensation above and below the curvature, the possibility of secondary fixed changes in the compensatory areas of the spine, all must be considered a part of the treatment problem. Treatment involves a great amount of effort on the part of the physician as well as the patient, and will cover long periods of time. It is imperative to have a good base-line examination to which subsequent examinations can be referred, to indicate either a lessening or an increase in the curvature.

As the structural deformity consists of many individually deformed segments, plus the secondary changes in the soft tissues, it is obvious that the problem is a very complicated one. The basic principle for treatment rests upon correction of the lateral curvature and derotation of the rotated vertebrae. The various forms of ingenious back braces, as well as corrective exercises, still leave a good deal to be desired in those cases that give roentgenographic evidence of curve progression. In spite of the great benefit obtained by improving muscle tone and body balance, the ambulatory patient will not, as a rule, obtain the improvement and correction desired. It is necessary to remove the

prone position. Hinges are incorporated near or over the apex of the curvature. After the jacket has been allowed to harden, it is cut out, turnbuckles are applied on the concave side and gradually opened, forcing the spine laterally from its ends while a counter force is maintained at the convexity.

Risser (1955) has shown that this method of correction is effective in all but the most severe and rigid types of curves. In addition to securing correction quickly it allows the patient to be ambulant preceding and following surgical fusion.

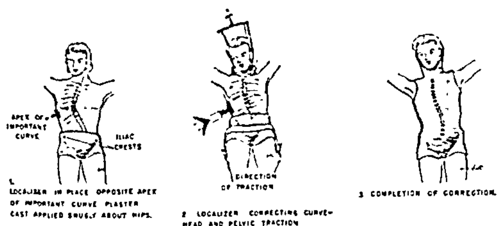


FIGURE 118. Correction by a Risser jacket with the localizer in position. Partial correction of the curvature is usually obtained by this method.

Risser has designed an apparatus (Fig. 118) that allows plaster application while the correcting forces are in play with the localizer body cast. The patient is placed supine upon the table, suspended by a canvas strap. Hip and knee flexion are maintained to eliminate lumbar lordosis. A well-padded plaster slab is moulded over the trunk at the apex of the curve. The pelvis is then enclosed in a plaster ring that is moulded well over the symphysis. Both the plaster ring and this slab at the apex are allowed to harden. When firm, traction is applied to the pelvic ring and countertraction is maintained by a chin-occiput sling. Pressure is then exerted laterally over the apex of the curve by the hardened slab. With suitable controls, the pelvis and lumbar spine can be tilted to either side as desired. Similarly, through control of the head, the cervical spine can be tilted to one or the other side as desired. These forces as applied provide correction through the deformed area of the spine. Plaster is then applied while the forces are maintained. They are released as the plaster hardens. Roentgenograms will show the amount of correction gained. If this is not as

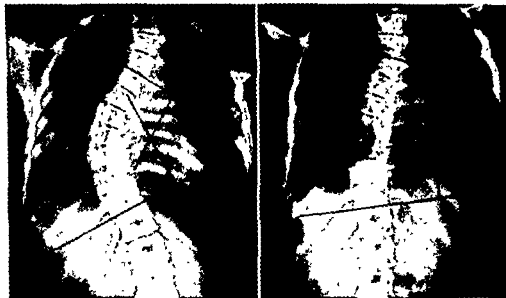


FIGURE 117. Rotary lateral curvature before treatment (*left*) and after treatment with Risser jacket and surgical fusion (*right*).

deviation from a line drawn connecting the centers of the two end vertebrae: (2) It is the vertebra with the greatest amount of wedging. (3) It is the vertebra of greatest rotation. Lines are then drawn connecting the centers of the end vertebrae with the center of the apex vertebra. The measurement of this angle represents the degree of deformity in the curve.

It is now generally held that exercises do not of themselves correct a rotary lateral deformity of the spine. They are important for maintaining proper muscle tone and for maintaining mobility in the spinal segments, and they serve to maintain contact between the physician and the patient. It has been shown repeatedly that a fixed lateral curvature of the spine can be corrected only by application of external force.

Various methods have been used to apply force in the correction of a scoliotic spine. In general, attempt has been made to apply force in two directions: one in which traction is applied in a longitudinal direction, as in stretching a rubber band; and second, a lateral force of correction, as one would apply in straightening a bent iron rod. Actually, many of the jackets and apparatus designed for one or the other of these methods of correction incorporate both of these principles. For the past 25 years, the hinged turnbuckle plaster of Paris jacket of Risser (Risser and Ferguson, 1936) has been used extensively. The jacket is applied with the patient lying either in the supine or

snugly over the pelvis while a head piece fits under the occiput and under the mandible. By the use of turnbuckles placed laterally, traction is exerted while at the same time a strap over the apex of the curve is tightened to achieve lateral pressure.

It has been shown that correction can be achieved by these various means. The method selected for the treatment of an individual case will depend upon the progression and severity of the curvature and the age and co-operation of the patient. In many cases it will also depend upon the surgeon's experience in the use of a particular apparatus. In one person's hand a certain method of correction may be entirely satisfactory, whereas in another, a different type of apparatus will achieve the same results.

Although these various methods of correction will of necessity vary with the surgeon, there are certain broad indications for their use. Thus, a turnbuckle jacket is indicated in severe, stiff types of curves in which considerable force will be necessary for correction. The light, ambulatory, anti-gravity type of jacket finds its usefulness in a child who has not reached complete growth. It may be desirable to carry its use through the period of growth before outlining definitive surgery, so as to control the curve during this period. The traction brace has found its greatest usefulness in the paralytic curve seen in anterior poliomyelitis. Unfortunately many of these patients cannot be ambulatory because of the extent of the paralysis. Also continuous pressure of the chin apparatus may give rise to growth changes in the lower mandible, but careful dental supervision will lessen this complication decidedly.

Surgical fusion. A curve once corrected by one of the above methods, when released from its restraint, will always tend to return to its original curvature, or to one of more severe degree. For this reason, some method of maintaining correction is indicated. At the present time, this is best accomplished by surgical fusion of the spine. Spine fusion may be carried out by one of a number of different methods (Campbell, 1956). Failure of any one of the segments to fuse results in loss of the correction, so that it is imperative that the fusion area be completely solid throughout its length. Selection of the spinal area to be fused is one of the most important considerations in the whole treatment. If incorrectly selected, a deformity as severe or more severe than that previously encountered may result. The minimum fusion area must always include the full extent of the primary curve that has been corrected. In many of the more severe cases in which absolute

complete as desired, the patient is allowed to remain in the primary jacket for several weeks. It is then removed and a new one applied in a similar manner. This process may be repeated several times before complete or adequate correction is achieved.

Wullstein in 1902 devised an effective method of forced correction. His method employed both traction and lateral pressure to the spine. More recently this method has been modified by the application of a jacket using an apparatus somewhat similar in design to that of Wullstein, but one in which the patient can lie supine on a canvas belt rather than sit upright on a stool. This method has also been shown to achieve effective correction in all but the most severe curvatures.

A third method of achieving correction has been the Milwaukee brace (Blount and Clarke, 1949; Fig. 119), using principles of longitudinal traction with lateral pressure. The brace is designed to fit



FIGURE 119. Milwaukee brace. The anterior upright (*a*) is made of aluminum to permit a roentgenogram of the spine to be visible, and the uprights are all adjustable at (*b*). The pad exerts constant pressure against the rotated ribs on the convex side of the curve (*c*). The dis-tracting force exerted on the head and pelvis should be just enough to stimulate the child actively to stretch the head upward and away from the chin and occiput piece. This active longitudinal stretching is considered to be of real benefit when wearing this type of brace.

Pathology. The pathologic changes are incidental to those of senile and debilitated states. The osteoporosis is marked throughout the vertebrae and the cortex becomes thinned. In the dorsal region, owing to the superincumbent weight, the vertebrae become wedge-shaped; while



FIGURE 120. Senile osteoporosis of the spine.

some of the vertebrae show a normal outline, the hourglass or biconcave outline is a characteristic feature, as is expansion of the disks into the adjacent bodies. There is roentgenographic evidence also of nucleus pulposus herniation when many vertebrae are involved.

Clinical Picture. Usually there is no history of trauma, although the well-known Sudeck atrophy is often initiated by trauma even though the loss of function is its chief cause. Pain may be severe upon spinal collapse and dorsal kyphosis. As a rule no neurologic evidences of cord compression are found. Chemical determinations usually reveal normal calcium, phosphorus and phosphatase. With a compression fracture, there may be a slight elevation of the phosphatase, and urine calcium tends to be increased.

Diagnosis. Diagnosis is made largely by exclusion of other pathologic states, such as primary or metastatic tumors, spondylitis deformans,

correction of the primary curve has not been achieved, it is necessary to extend the fusion above and below into the secondary curves in order to obtain optimum trunk balance. It is usually necessary to carry out the spine fusion in two or more procedures; fusion of more than six or seven vertebrae at one stage is rarely desirable.

Postoperative convalescence. Following surgical fusion, the spine must be maintained in the corrected position until evidence of successful fusion is present. This is determined by serial roentgenographic examinations of the fusion area. The minimum period is usually 9 months but may extend longer. During the latter part of convalescence, provision is made for some type of ambulatory jacket or brace. If fusion has failed at one or more levels, the roentgenograms will show progressive loss of the original correction. Such loss means that the spine will have to be corrected again and the area of failure explored and repaired.

Following removal of all restrictive apparatus, the patient is started on a program of muscular exercise to improve the muscles of the spine and abdomen. In young persons in whom this lengthy procedure is carried out, this is usually not a difficult feat and they quickly return to normal activity. The period of observation must continue, however, until complete growth is attained or until the spine is definitely shown to be stabilized. It should be remembered that the mobile secondary curve will later assume the same degree of correction that has been obtained by straightening and fusing the primary curve, according to the law of compensatory forces. This type of treatment requires many months of effort by the physician and patient, so to repeat, a complete understanding of this by the patient is essential at the beginning of treatment.

Senile Osteoporosis of the Spine

Senile osteoporosis of the spine presents extreme decalcification of the bones and is seen in the adult and in some degree in all old people (Fig. 120). It gives rise to vertebral deformities and involves the dorsal and lumbar regions more frequently than the cervical. Women are four times as frequently afflicted with this condition as men, owing probably to menopausal changes. It probably does not arise primarily as a disorder of calcium and phosphorous, but as a deficiency in the continued formation of the protein matrix by osteoblasts. In *normal* bone the deposition and resorption of calcium and phosphus is equal, while osteoporosis is a true atrophy of bone tissue and the loss of function of a part causes osteoporosis of the whole limb.

pressure of superincumbent weight. The degree of angulation of the spine (kyphos) will be determined by the extent of the underlying disease of the vertebrae.

If one vertebral body is destroyed, the kyphos will be sharply angulated (Fig. 121). If several are involved, it will be less sharply angulated. If the disease is in the extreme cephalic or caudal portion of the spine, the projection of the spinous process (kyphos) will be slight because the amount of the spine involved is small compared to the percentage of spine free from disease. Therefore, it may be difficult to recognize the disease by the deformity at either end of the spine.



FIGURE 121. Patient with Pott's disease. Note severe kyphosis

Rarely does the infection begin in the lamina or spinous process, for usually the posterior part of the spinal column remains free from disease. The intervertebral disks are more resistant to the affection than the osseous structures, though the fibrocartilages in the late stage will disintegrate and disappear following bony disease of the body above and below. Early in the disease one may detect a thinning of the intervertebral disk and decalcification of the vertebral body or bodies.

Following the destruction and collapse of the vertebrae, the outcome

hyperthyroidism or hyperparathyroidism, all of which may simulate senile osteoporosis. However, in the elderly person a generalized osteoporosis, the thinned but usually intact cortex, the normal blood values and the absence of a primary focus are all characteristic of senile osteoporosis. The history and roentgenographic and laboratory findings should make the diagnosis clear.

Treatment. The age period in which this affection occurs necessitates confinement to bed or wheel chair for life for some of those afflicted, although prolonged recumbency must be combatted. The use of a very light plaster jacket or back brace may relieve the pain and is preferred when possible. A well-balanced diet is advisable, one rich in calcium, phosphorus and vitamin D, but rarely can much recalcification be demonstrated by roentgenogram. The dietary regimen and back support must be continued indefinitely. It has been suggested that calcium gluconate, aluminum acetate or magnesium carbonate may be of value, although conclusive evidence is lacking. Albright recommends the use of sex hormones; women given testosterone initially, but maintained on estrogen; men given estrogen initially and maintained on androgen.

DISEASES

Tuberculosis (Pott's Disease)

It must be constantly remembered that tuberculosis of the bones and joints is a local manifestation of a generalized disease. Statistics show that tuberculosis more commonly involves the spine than any other portion of the skeletal system. While 70 per cent of the cases occur in persons between the ages of 3 and 10, the disease is not rare in adults. Therefore, tuberculosis of the spine may occur in any period of life. Pott's disease, named after Percivall Pott who first described the condition in 1779, consists of caries of the spine produced by the bacillus of tuberculosis.

Pathology. Owing to the peculiar inaccessibility of the pathologic process, Pott's disease is fraught with serious complications because of the secondary effects of deformities on the vital organs anteriorly and the spinal cord posteriorly. The anterior part of the vertebral bodies just beneath the anterior longitudinal ligament is usually the site of the initial osseous lesion. The granulation tissue advances along the front of the body of the spine, following blood vessels and invading the underlying bone. The destructive process honeycombs the vertebra or vertebrae and finally the diseased body or bodies collapse under the

holding his body stiffly as though "treading on eggshells." With advanced disease of the cervical region the head assumes a wryneck attitude and the chin is frequently supported and steadied by the hand. With disease in the dorsal region the body may even be bent forward, the body being supported by a hand held on the knee. Instinctive protection of the affected part is characteristic.

The symptom of pain is by no means constant, but it is induced by jars or by sudden unguarded movements; often these occur at night. At this time the relaxation of the muscles splinting the part occurs and sometimes causes the patient to wake with a scream — the so-called "night cries."

If the patient is a child, greater co-operation may be obtained by having the mother direct the child to carry out these suggested movements. In the early cases several examinations may be necessary before the presence or absence of disease can be definitely determined by physical examination alone.

Following inspection on activity the child should be placed upon a low, hard table and the spine carefully palpated. Localized tenderness at the level of the affected vertebrae is not constant, for as the disease affects chiefly the bodies of the vertebrae it is obvious that the examiner is palpating at a comparatively distant point from the site of the disease. Loss of normal contour of the spine indicative of underlying bony destruction may be seen however; the early cases may be more easily detected by noting an irregularity of the spinous processes when running the fingers down the spine. Another point of diagnostic significance, in addition to muscle spasm, is a feeling of induration of the underlying tissue on either side of the spinous processes when palpation is made along the median furrow of the back.

Passive movements of the suspected portion of the spine should be made while the patient is lying on his abdomen, and this can be done by gently raising the thighs off the table and moving the body to and fro laterally. The patient should then be turned over on his back and the abdomen carefully examined for abscess formation. If the disease is suspected in the cervical region, a careful and gentle manipulation of the head in all directions will elicit pain and a feeling of resistance. At this site a retropharyngeal abscess may interfere with respiration and deglutition. In the thoracic region the affliction may be mistaken for pleurisy or empyema. On palpation of the abdomen with the patient's hips and knees flexed a firm sausage-like mass, which is the outline of the abscess, will often be felt.

is largely dependent upon the treatment received and the general resistance of the patient. Rarely is cure without deformity effected, but if the disease is moderately inactive, bony union may occur naturally. Unfortunately this happy outcome is not the rule; the tuberculous process usually extends itself locally, involving the coverings of the spinal cord and giving rise to large abscesses which burrow along muscle planes. These abscesses may cause a pressure paralysis and result in paraplegia.

Owing to the greater strain to which the middle and lower parts of the spine are subjected, the dorsolumbar area is the most frequent site of infection. The dorsal region, which constitutes approximately 50 per cent of the length of the spine, is also frequently involved; the cervical spine is the least often involved.

Clinical Findings. Children afflicted with Pott's disease are often underweight and are frequently in poor general condition. Although an obvious sign of the disease is angular deformity of the spine (kyphos), certainly the condition should be detected before angulation becomes evident. A destructive lesion of a vertebrae manifests itself by pain, weakness and impairment of normal motion. As the disease occurs in close proximity to the spinal cord, it is to be expected that patients early show local neurologic signs and symptoms of involvement of the central nervous system.

In examining the patient one should always try to learn "when the child was last perfectly well." One should determine by questioning whether the symptoms complained of are acute or chronic; whether there is a history of tuberculosis in the family; and whether the history of previous disability appears to be related to the present disability.

Careful inspection of the prepared patient should then be made with the patient undressed in order that his general posture may be noted. The contour of the spine should be observed, since slight irregularities at the area involved may appear early.

A careful examination of the range of motion in the affected spine always reveals limitations. The patient should thus be asked to bend over to pick up some small object, and any change from the normal flexibility should be carefully investigated. When making this movement the knees are bent while the affected spine is held rigid. Early evidence of limitation of motion can be detected most easily in the lumbar and cervical regions.

The physician should next note the patient's attitude when walking. A patient with tuberculosis of the spine walks with short steps,

shadow (Fig. 122), indicates the outline of the local abscess about the vertebra and as this shadow persists well into convalescence, its increase or decrease in size and capacity may be a prognostic sign. Laminagraphic examination is often of diagnostic aid.



FIGURE 122. Pott's disease, showing fusiform abscess with collapse of the body of the diseased vertebrae.

A notching of anterior borders of the vertebrae about the middle of the body may occasionally be noted in young children, but this should not be mistaken for evidence of disease. It is incidental to the early development of the vertebrae and represents noninfectious changes within their bodies.

Differential Diagnosis. It is in the early cases of tuberculosis of the spine in which there is no definite roentgenographic evidence of disease that the greatest difficulty in diagnosis is encountered.

Osteomyelitis may be produced by a number of organisms other

In the early cases of Pott's disease in the lumbar region, there is always some contraction of the psoas group of muscles, and complete extension of the hip is resisted and causes pain. When an abscess forms in the iliac fossa, it may affect locomotion. *Paraplegia* is a late complication and is a result of extension of the disease and pressure of the diseased and edematous tissue upon the spinal cord in the presence of vertebral angulation.

Tuberculin tests (the Mantoux or the patch test) should always be made on any young patient suspected of having Pott's disease. In the presence of a roentgenographic examination showing no abnormality and a negative tuberculin reaction, even though local irritation is manifest by muscle spasm and there is limitation of motion, one is not justified in attributing the joint irritation to tuberculosis. With indefinite roentgenographic evidence combined with a marked positive tuberculin reaction and muscular rigidity of the spine, the diagnosis of Pott's disease is fairly well established. It is, of course, most important to make the diagnosis as early as possible, and if a careful clinical examination suggests disease and the tuberculin reaction is positive, the case should be regarded as one of tuberculosis until proved otherwise, even in the absence of positive roentgenographic findings. If deformity has occurred, the degree of bony destruction should be confirmed by roentgenograms. Physical examination and roentgenographic studies of the chest should be performed routinely, although only a small percentage of bone and joint tuberculosis shows active pulmonary lesions. With pulmonary complications, the outcome is much more grave than in cases without such involvement.

Roentgenographic Findings. Very early in the disease, definite evidence of bone destruction is lacking, but whenever there are clinical signs and symptoms suggestive of spinal disease roentgenograms should invariably be made. The original films may also be valuable for comparison with subsequent pictures. Both anteroposterior and lateral exposures should be made routinely. Irregularities, with bone destruction of the anterior edges of the vertebrae, are characteristic; a wedging of one or two bodies with narrowing of the joint space subsequently develops. An anteroposterior view may show not only the localized evidence of disease but also secondary deformities. The ribs are no longer parallel to each other posteriorly but tend to radiate from the diseased area as the spokes of a wheel, and in late cases the bodies may form a mass with no intervertebral space showing. Perivertebral thickening, which shows early in practically all cases as a fusiform

Spondylolisthesis also may be confused with Pott's disease, as well as certain forms of organic disease of the spine other than tuberculosis. Congenital anomalies other than spondylolisthesis in the absence of roentgenogram may cause confusion occasionally.

Complications. *Abscess.* In every case of Pott's disease the tuberculous destructive disease forms a liquefied fusiform-shaped mass or area about the site of the diseased vertebrae, which can be identified in the anteroposterior roentgenogram whenever the disease is in its active phase. An abscess often may cause no symptoms and exist for months before its presence is detected. As this "cold abscess" enlarges, it distends its walls and burrows along the muscle planes to appear on the surface of the body. Therefore, these abscesses may "point" as fluctuant swellings at distances far removed from the spinal disease or may rupture, producing draining sinuses which soon develop secondary infections. In lumbar Pott's disease the abscess may burrow under the psoas muscle and be palpated as a sausage-shaped mass in the pelvis in Petit's triangle, under Poupart's ligament, or collect as a large bag of purulent fluctuant material in the thigh. If not detected early and aspirated, they will often rupture through the skin. If they occur in other regions their distention will cause symptoms of mechanical obstruction, such as a retropharyngeal abscess which may obstruct breathing and swallowing. Prompt incision and drainage in this location is necessary.

Paraplegia complicating Pott's disease is always serious and is produced by pressure of the tuberculous detritus and diseased edematous tissue against the spinal cord. The degree of angulation or gibbus produced by the collapsed vertebral bodies may be severe without paraplegia developing, provided the bony collapse develops slowly. The bony angulation is not the main factor; far more important is the pressure of the soft tissues and abscess against the spinal cord. In fact, paraplegia more frequently accompanies slight or moderate bony deformity than severe collapse of the vertebral bodies. This direct soft tissue pressure also produces circulatory embarrassment with local edema of the cord.

The liability of paralysis developing is greatest when Pott's disease involves the middle and upper thoracic area, especially from the third to the seventh dorsal vertebra.

In such cases laminectomy is rarely advisable, although occasionally it seems to be of some value in the adult. Uninterrupted, prolonged recumbency on a hard mattress or slightly convex Bradford frame

than *Mycobacterium tuberculosis,* chief of which is *Staphylococcus aureus.*

Osteomyelitis of the vertebrae, when an acute process, behaves as an active infection elsewhere. It is ushered in by the usual constitutional symptoms of a sudden elevation of temperature and leukocytosis, while the local signs and symptoms reveal an acutely sensitive spine with restriction to any activity.

The roentgenogram during the first week or ten days reveals very little of significance, but when the process becomes chronic characteristic changes develop. The joint space is then narrowed and in the vertebral bodies the destructive process is mingled with a proliferation of bone about the margins of the diseased vertebrae. A zone of sclerosis can be seen on the affected vertebrae and as a rule the roentgenogram has a sharpness of detail and absence of abscess formation unlike a tuberculous process. This type of osteomyelitis is rarely seen in children.

Acute abdominal conditions may at times cause confusion, although the chronicity of all tuberculous lesions is distinctive. Rigidity of the spine occurs fairly often in cases of appendicitis, inflammation of the retroperitoneal lymph nodes, pyelitis, and other inflammatory abdominal affections. A careful history of onset with blood count and temperature chart will usually clarify the diagnosis.

A *sprain* or other type of back injury may be confusing, for a child with such an injury may present all of the clinical evidence of early tuberculosis of the spine, such as pain, rigidity and abnormal attitude; the history, roentgenogram, temperature and tuberculin reaction will be of diagnostic aid in this instance.

Disease of the hip joint may sometimes be confused with Pott's disease in the lumbar region in a casual examination of a child. However, an examination of the hip joint movements with the child on the examining table should make the differentiation between hip joint disease and spinal disease easy.

In the actively *rachitic* child the condition of the spine may resemble that due to tuberculosis, but tuberculosis of the spine is uncommon in children of the age at which rickets usually begins. Also, the rachitic curve is rounded instead of angular as in tuberculosis, and usually there are evidences of the generalized deficiency disease.

In certain cases of Pott's disease in the lower lumbar vertebrae, the awkwardness in walking and extreme lordosis may be mistaken for *pseudohypertrophic muscular dystrophy.*

(Fig. 123) is used. In addition to this, head traction (Fig. 124) in cervical Pott's disease is employed.



FIGURE 123. Type of frame used for cervical Pott's disease.

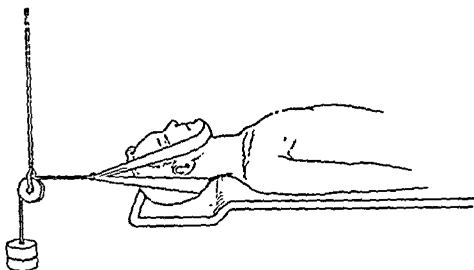


FIGURE 124. Head traction, as used for cervical Pott's disease.

As already stated, the majority of orthopaedic surgeons favor operative fusion of the affected area following a few months of conservative treatment, and then several months convalescence in bed. It is desirable, however, not to operate upon a child younger than 10 years of age. When the disease is acute, as shown by pain on movement, muscle spasm, temperature elevation and allied symptoms, it is absolutely futile to fit the patient with any type of ambulatory support. No brace or plaster jacket can as effectively relieve the parts from stress and strain as recumbency. Following operation, however, and when the patient is out of bed, the spine should be supported until fusion is complete by a plaster jacket or brace. If the spinal disease involves the vertebrae above the tenth dorsal vertebra, any form of mechanical support is ineffective unless the chin and head are supported by a brace with a chin attachment, or the so-called Calot plaster jacket.

combined with streptomycin daily usually gives the best opportunity for return of function.

Meningitis as a complication of bone and joint tuberculosis is fortunately rarely encountered, and when it does occur, it is usually in children. There is a sudden onset of listlessness with a rapid rise in temperature to 103° to 104° F. There is loss of appetite and sometimes projectile vomiting. A stiff neck and a positive Babinski develop.

Previously there was a 100 per cent mortality in tuberculous meningitis but recently cases have been reported that have recovered following large doses of streptomycin.

Myeloid disease rarely occurs today and if it does, the mortality is high.

Treatment. The general treatment of tuberculosis of the bones and joints has been mentioned previously (see Chapter 2), but again it must be emphasized that the local lesion is evidence of a systemic tuberculous disease and every effort should be made to treat the patient as a whole. This means that whatever the method of treatment chosen for the local lesion, the patient should have a preliminary period of body building and rest in the attitude of recumbency with the spine in slight hyperextension. Formerly emphasis was placed only upon the mechanical treatment, but now the use of the antibiotics preliminary to and after operative treatment has taken precedence over continuous nonoperative care. However, even the proponents for the operative treatment of joint tuberculosis feel that much is to be gained by following carefully the conservative mechanical principles over a period of a few months before operative fusion is undertaken. If possible, operative fusion should be delayed until the child has reached the age of 10.

Since weight of the body above the site of the lesion is a constantly active force which must cause increasing compression with nerve irritation and increasing bone deformity, it follows that recumbency removes the effect of gravity and gives more rest to the diseased parts. Horizontal fixation is most effectively and conveniently employed by the use of a Bradford frame or an adjustable type of spinal frame, permitting gradual extension at the point of disease. The methods of promoting absolute recumbency in order that the rest may be "prolonged, continuous and uninterrupted" are many, but it is advisable that, whatever individual method used, the shoulders remain flat against the frame and the lumbar and thoracic portions of the spine be immobilized as far as possible.

If the cervical region is involved, a slightly different type of frame

without evidence of pulmonary involvement, and operation under these conditions is rarely indicated. Fusion of the spine is best reserved for older children and adults; seldom, as has been previously mentioned, does one advocate fusion in young children.

Relapses with recurrences of spinal symptoms, due to development of postoperative pseudarthroses or rapid progression of the local disease, occasionally occur. One must be warned, therefore, against an unwarranted confidence in the absolute effectiveness of the operative method. Any method of treatment in tuberculosis of the spine must be long continued in order to effect a cure. Relapses do occur many years after apparent inactivity of the disease whether the nonoperative or the mechanical plus the operative methods of treatment are followed.

Roentgenograms should show bony ankylosis before one can feel confident that the disease is arrested or before the supportive treatment can be discontinued, for the active individual is always subjected to the deforming tendencies of gravity and superincumbent weight.

Any patient with tuberculosis, whatever the structure involved, even one with clinical and roentgenographic evidence of healed tuberculosis, should be occasionally checked by roentgenograms, and some restriction placed on his physical activity.

Tuberculosis of Ribs

Tuberculosis of the ribs is rarely encountered. It is largely a disease occurring in persons between 15 and 30 years of age. It may be that the ribs and cartilages become secondarily infected from the adjacent lungs, peripheral lymphatic glands or vessels; these lesions must be regarded as hematogenous metastases. The development is insidious. There is a slight thickening of the tissues over the affected region, with or without abscess formation.

Treatment. Treatment consists of radical resection of the affected rib and cartilage with closure of the wound.

Tuberculosis of the Sternum

Little reference is made to tubercular involvement of the sternum, and it undoubtedly is rare. It has been reported as secondary to active pulmonary tuberculosis, manifesting itself by local swelling and fluctuation. Repeated aspiration may suffice, or if the abscess ruptures and continues to drain, heliotherapy and streptomycin may be tried to improve or cure the local condition. The prognosis must be guarded. Radical surgery is hazardous.

Operative treatment for Pott's disease in childhood must follow a preliminary observation period of the patient which should last several months, or even longer. During this time the patient should remain in the recumbent attitude and receive antibiotics, a nutritious diet, vitamins, sunshine and other measures as indicated. After this observation period the operative fusion of the whole area, including in the fusion two vertebrae above and two below the diseased area, is executed. The special technics devised by Hibbs (1912), Howorth (1943), Albee (1915), Forbes (1920) and others may be employed. The general principle is the same with whatever method used; that is, if splinting the spine by means of some external support is partly effective, it may logically be reasoned that internal fixation by an operation will be even more effective. Advocates of the operative method believe that the patient will obtain bony union at the area of disease very much more rapidly by an operation which assists Nature than by keeping the patient in the horizontal position long enough to permit the diseased area to heal by the tedious process of calcification and natural bony fusion. In adults a shortened period of recumbent immobilization becomes a decided economic advantage and here early fusion is recommended.

The Hibbs' and Forbes' types of fusion utilize the bony chips obtained from the laminae and spinous processes; additional bone can be removed from the posterior iliac crest. Also, by removing the cartilage from the interarticular facets, there is a fusion of the posterior segments of the vertebra. The surgeon in the Albee type of fusion splits the spinous processes and places a graft, usually obtained from the tibia, into these clefts, thereby promoting immobilization in the operated area.

Although these operative measures shorten the period of convalescence, it should be emphasized that rest in the horizontal position for 3 to 4 months following operation should be employed. Only after roentgenographic evidence shows that bony fusion is progressing satisfactorily should ambulatory treatment be permitted. The patient is fitted with some type of supportive apparatus during his convalescent and ambulatory phase.

Prognosis. Although the operative method as described is the preferred treatment for tuberculosis of the spine, it must be remembered that the procedure is not without complications. A small percentage of patients with joint tuberculosis may have pulmonary lesions and if fusion becomes necessary, it should then be done under local anesthesia. These patients undoubtedly do not do so well as those

Treatment. In the acute stage treatment consists of chemotherapy, immediate evacuation and drainage of the abscess if accessible, and support to the spine during subsequent stages.

Nontuberculous osteomyelitis may attack the ribs or sternum and follows the same course as osteomyelitis of other portions of the body. It is rarely primary in the ribs or sternum, though disease of the ribs from an adjacent empyema is not unusual. Incision and drainage, if feasible, is the treatment of choice if the sternum is involved. In the ribs complete excision of as much of the diseased portion as possible should be done.

Typhoid Infection

The typhoid spine or typhoid infection of the ribs may occur as a complication in about one to every 1800 cases of typhoid fever. It is most common in young males. The diagnosis is usually made clear by the history of typhoid fever, if after or during the course of this disease the patient develops symptoms of pain, weakness, stiffness of the back, or localized tenderness and swelling over one of the ribs.

Treatment. The acute symptoms usually subside following rest in the recumbent position or with some form of support. Complete recovery without surgery is the rule; however, excision of the affected rib or drainage of the spinal abscess should be done if necessary.

Syphilis

In central nervous system syphilis the vertebrae are sometimes affected, resulting in local deformity somewhat grossly resembling that of Pott's disease. Charcot's joint in the spine may develop, presenting a destructive, painless osteoarthritis. In some respects syphilis is similar to an arthritis deformans in its pathologic manifestations but is more destructive. With the cartilage degeneration, the underlying bone is worn away and there is an exaggerated and irregular formation of cartilage and bone, as a rule involving several vertebrae.

A sudden onset, with deformity and absence of severe pain, is characteristic. It is reported that 5 per cent of ataxic patients have a Charcot's joint, and although it is more common in the lower extremities, especially the knee, Charcot's disease of the spine (Fig. 126) is occasionally seen. The prognosis is poor, for the destruction is usually of a progressive type.

Treatment. Antisyphilitic treatment should be instituted. Treatment must also be directed toward splinting the spine with a brace or other

Osteomyelitis

Osteomyelitis is essentially a disease of the shafts of the long bones, occasionally affecting the joint surfaces by direct extension (see p. 55). Acute osteomyelitis of the spine is relatively uncommon; it does, however, occur and the symptoms are similar to those of an acute infectious process elsewhere. The bodies of the vertebrae are usually involved, the thoracic region being most frequently affected. Localized pain, fever and constitutional symptoms with early abscess formation are noted in this condition. In the acute cases *Staphylococcus aureus* is the usual infective agent and its tendency to metastasize always makes the outlook grave. The original focus of infection may be a furuncle, skin abrasion or infection elsewhere in the body. The chronic forms may be caused by a variety of organisms such as *Eberthella typhi* (*Bacillus typhosus*), *Diplococcus pneumoniae, Actinomyces bovis, blastomycetes* or *Brucella melitensis.*

Osteomyelitis of the spine is insidious and is not usually diagnosed before the roentgenogram (Fig. 125) reveals destruction and proliferation of bone.



FIGURE 125. Osteomyelitis of body of fourth and fifth lumbar vertebrae. Note bony column posteriorly including third, fourth and fifth lumbar vertebrae to sacrum following surgical fusion

Vertebral Epiphysitis (Scheurmann's Disease)

Under postural deformities are discussed those cases of round back which develop from muscular imbalance. The term "vertebral epiphysitis" has been applied to another type of dorsal kyphosis. Clinically this condition is seen in persons between 10 and 25 years of age. It is accompanied by fatigue and pain in the back and limbs. The condition is probably pathologically similar to those other epiphyseal disturbances such as Legg-Perthes' disease of the hip and Köhler's disease of the tarsal scaphoid. The rachitic spine, which may have a dorsal kyphosis deformity, is discussed in Chapter 2.

In vertebral epiphysitis a number of contiguous vertebrae of the dorsal spine are involved. Roentgenograms will afford differentiation between this and the round shoulders and hollow round back deformity sometimes seen in persons with poor posture alone. Clinically the symptoms are milder than in tuberculosis; the curvature is a well-rounded one and not a sharp angulation; the roentgenogram makes the differentiation clear.

In addition to the obvious deformity, pain on pressure over the spinous processes will be noted, and roentgenograms (Fig. 127) reveal a disturbance in the ossification of the epiphyses of the bodies of the vertebrae, which appear irregular in outline, particularly on the anterior edges, and fragmented in the early stages of the disease. The intervertebral spaces are cloudy and the surfaces of the vertebral bodies rather indistinct. The process is a self-limited one. As healing takes place the bone outline becomes relatively more distinct but remains irregular. If the deformity is not corrected in the early stages, it may progress to the point of a permanent disability.

Treatment. In the early and painful stages treatment should consist of recumbency and later, corrective support with exercises. Rarely does the condition require operation, but occasionally the area of deformity is so severe and progresses so rapidly that a fusion operation should be performed after the optimum correction has been obtained by recumbency on a convex frame.

Vertebral Osteochondritis (Calve's Disease)

This rare condition, first described by Calve in 1925, usually develops in children between 5 and 10 years of age It is associated with pathologic changes suggestive of avascular necrosis, usually of a single vertebral body. Clinically it presents a picture similar to that of Pott's disease with night cries, muscle spasm and local tenderness, but the

protective device such as a plaster or celluloid jacket. Rarely is a spine fusion indicated.



FIGURE 126. Charcot's disease of the spine.

Actinomycosis of the Spine

This is a very rare condition and the diagnosis can be positively made only by finding the characteristic sulfur granules on microscopic examination of the discharge from the sinus. It is seen most frequently in the jaw.

Treatment. This consists in a trial of large doses of potassium iodide.

Blastomycosis and Undulant Fever

These diseases occur rarely (Chapter 2, pp. 66, 69). They run a chronic course and do not present pathognomonic roentgenographic features. The diagnosis must be confirmed by laboratory data and the constitutional signs and symptoms are not characteristic.

Arthritis

Both the osteoarthritic and rheumatoid types of arthritis are discussed in Chapter 2.

but not very often, found in the spine. Hodgkin's granuloma may involve the bone marrow, favorite sites being the vertebrae and pelvis. A bone tumor more commonly involving the spine than any of the above is a multiple myeloma. This not only produces extensive involvement of the skeletal system, but its systemic manifestations are widespread.

The clinical picture in a spinal cord tumor may closely simulate that associated with many back pain conditions, and a neurologic consultation should be obtained. The differential diagnosis is especially difficult if these cord tumors involve the cervical region.

The spine is also frequently the site of metastasis from carcinoma of the prostate, breast, kidney, gastrointestinal tract or lungs, in the order named. (See Chapter 16.)

SOFT TISSUE INJURIES

Lumbosacral and Sacroiliac Strains

The frequency with which low back pain is encountered in human beings makes it a subject of very practical interest to every physician. By general usage, this term is often regarded as a diagnosis, although it is only the localization of a symptom. In this chapter (p. 158) there is an outline under the heading Low Back Pain Syndrome, which should be kept in mind and routinely consulted in differentiating between the various causes that may play a part in the development of backache. Age, sex, body build, and occupation are important factors in low back pain problems. In younger age groups stresses and strains predominate, whereas in the older group degenerative changes with or without congenital anomalies may be superimposed upon diseases and injuries of the skeletal system.

Pain is Nature's message of warning and means some disturbance from the normal, whether it be functional or structural in origin. Often the cause of a regional pain of this sort cannot be localized to one joint, but may arise from a variety of conditions whose origin may be postural, traumatic, infectious, or some other basic pathologic state.

Undoubtedly a very large proportion of low back pain is due to imbalance of body posture in relation to the center of gravity—changes that arose in the redistribution of body weights when the human assumed the upright attitude instead of the quadruped type of balance. The body weight in the four-legged animal hangs vertically from the horizontal spine, so that the weight is supported by four

prognosis is much more favorable. Lack of abscess formation and the absence of a positive tuberculin reaction are both aids in differentiating it from Pott's disease. The roentgenograms show a flattening of the central osseous nucleus and a conspicuous increase in density.



FIGURE 127. Old uncorrected vertebral epiphysitis showing severe permanent deformity.

Treatment. During the acute stage in which there is pain and muscle spasm, a period of recumbency with the spine hyperextended should be prescribed. The condition will have a favorable course under proper conservative treatment.

Bone Tumors

Primary bone tumors involving the spine are unusual. Benign chondroma may involve the ribs and sternum and grow to considerable dimensions. Patients with benign chondroma or chondromyxoma are often adults between the age of 20 and 30 years. Ewing's tumor of the vertebrae has been reported, but the more frequent sites of this tumor are in the bones of the lower extremities and the upper third of the humerus. Giant-cell tumor and hemangioma are occasionally,

involved. As a rule, differentiation between the two is not difficult; occasionally, it may prove very difficult. When evidence by the roentgenogram is lacking to aid in the differentiation, we must fall back on the history and clinical findings. A rectal examination must be routine.

Clinical Picture. In sacroiliac joint involvement, the pain complained of is usually referred down the back of the hips and thighs; in lumbosacral strain it may also pass down the front and outer side of the thigh and leg.

Lumbosacral strain will usually present localized pain on pressure over the tips of the fourth or fifth lumbar vertebra, at the lumbosacral joint or the iliolumbar angle; in sacroiliac strain, pain is more definitely localized along the posterior border of the ilium, directly over the sacroiliac joint.

In lumbosacral affections, the muscle rigidity of the spine is usually marked. If compression of the iliac crests causes pain, it indicates sacroiliac rather than lumbosacral involvement.

In sacroiliac involvement, abnormal abdominal pressure over the affected sacroiliac joint (*Baer's sign*) is clinical evidence that the lesion is in the sacroiliac rather than the lumbosacral region. The patient with sacroiliac trouble usually cannot lie with comfort on the affected side, and there may be pain on pressure at the sciatic notch or over the posterior superior spine.

In sacroiliac strain, if the patient is examined while sitting the movements of the lumbar spine are usually free and painless, whereas in lumbosacral involvement all the movements of the spine are restricted and extension of the straight legs causes as much pain as flexion.

Roentgenographic Findings. Roentgenograms in lumbosacral or sacroiliac strain may be of comparatively little positive value. The lateral view of the lumbosacral joint may give evidence of an increased lumbosacral angle suggestive of increased shearing forces of stress and strain at that joint, or there may be a narrowing of the disk space indicative of a beginning localized arthritis.

Occasionally a definite degree of motion can be demonstrated in the sacroiliac joint; it is, however, extremely slight, so the diagnosis of mechanical displacement should be made with great care and should be checked by roentgenogram, using the Chamberlain test (Chamberlain, 1932; Fig. 128), noting symphysis pubis displacement when bearing weight on first one foot and then the other. Actual movement or displacement occurs infrequently and many of these low back pains are postural in type. Oblique, lateral and anteroposterior views should be

pedestals. The beast of burden controls his load by the strength of his hind-quarters' pulling power, and this is really accomplished by pushing his whole weight against the harness, using to a large degree his powerful abdominal muscles.

The total result of the change from the quadruped to the biped form of existence is to make the body balance more easily disturbed. As the weight in the upright position must pass through the flexible intervertebral disks as well as the vertebral bodies, there is a constant occurrence of greater stresses and strains which are not present in the quadrupedal position. This upright attitude of the spine also tends to produce visceroptosis and lordosis. The finely balanced spring action in those animals with well-developed abdominal muscles is lessened whenever there is an abnormal increase in the distance between the pubic region and the sternum. If the abdominal wall in the human were bridged by bone, our movements would be seriously restricted, but at the same time many of the sequelae of stress and strain which we interpret as chronic backache would be reduced. It is hoped, therefore, that a better appreciation of the balanced forces in body posture may permit us to understand some of the causes for back pain. Our body structure responds to the stresses and strains put upon it to a remarkable degree, and up to a point compensates well. Then, like heart muscle, it becomes decompensated. It can no longer carry the load without symptoms of fatigue. Many books have been written upon this subject and a few references to these are appended at the end of this chapter.

Examination. A careful examination of the spine and the various laboratory aids in diagnosis have been outlined earlier (pp. 152–159). It must be mentioned, however, that although the value of roentgenographic studies cannot be overestimated, they can never replace a careful physical examination. Indiscriminately ordering roentgenograms and having them interpreted by the roentgenologist who has not the clinical picture available upon which to base his findings has led to confusion for the doctor and trouble for the patient.

In a consideration of low back pain in the young adult the signs and symptoms that will aid in differentiating between lumbosacral and sacroiliac strain should be considered In the first place, it must be remembered that the lumbosacral joint is more frequently the cause of low back pain than the sacroiliac joint and the popular diagnosis of "subluxation or relaxation of the sacroiliac joint" should be made with great care. Both of the above joints are very rarely simultaneously

the exit of the spinal nerves from their foramina. In the true neuritis, rest in the recumbent attitude gives little relief.

Another difficult type of patient is the individual who is receiving compensation, and in these the symptoms are likely to be exaggerated and the convalescence prolonged.

Treatment. If the backache rests upon a definite pathologic background (Fig. 129), the underlying cause must be recognized and treated (see classification under Low Back Pain, p. 158).

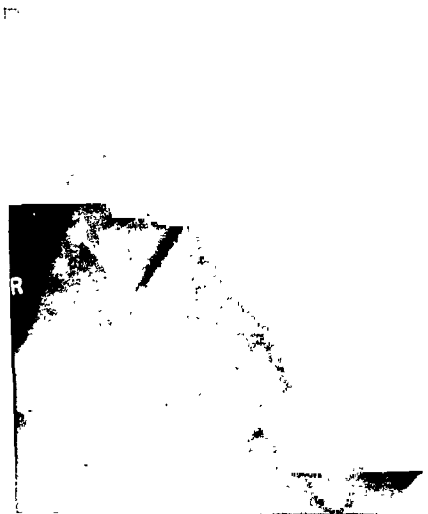


FIGURE 129. Narrowing and roughening at lumbosacral joint giving rise to lumbosacral arthritis. This is a cause for low back pain and sometimes necessitates fusion of the fifth lumbar and first sacral vertebrae.

Conservative treatment. Under nonoperative treatment we can consider the mild case without roentgenographic evidence of injury in which exercises designed to improve body balance and strengthen the muscles, particularly the abdominal group, may be indicated (Fig.



Figure 128. Chamberlain test for mild sacroiliac relaxation. This is not pathognomic, but may be useful in differential diagnosis of lumbosacral disabilities.

routinely obtained; occasionally, after consultation with the roentgenologist, special views such as bending films (flexion, extension and lateral bending) should be secured.

Mental, emotional or physical fatigue may complicate the clinical picture. Thus, in a great number of patients between 20 and 40 years of age a careful clinical and laboratory examination will fail to reveal any pathologic osseous basis for the persistent low back pain, and in these cases certain general points should be stressed.

In the patient with a long history of suffering or discomfort in which various forms of treatment have been tried without benefit, definite anxiety-tension neuroses may have developed. In these cases the examiner will be rewarded by a grateful patient if he will take the trouble to go carefully into the personal conflicts of the patient as related to his daily work and domestic life. Many times these patients are wound up mentally and physically and careful analysis and sympathetic advice regarding their daily routine may produce unexpectedly satisfactory results without any drastic form of treatment.

True sciatica, that is, a *neuritis of the sciatic nerve*, is a comparatively rare finding, and many times we loosely apply this term to those patients with backache who complain of pain along the posterior portion of the thigh in the region of the sciatic nerve. Many patients with sacroiliac or lumbosacral strain as well as rupture or protrusion of the intervertebral disk complain of pain in this region, but it is not true sciatica; it is rather a radiculitis caused by nerve irritation near or at

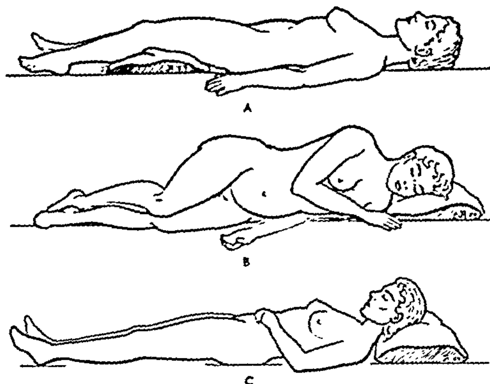


FIGURE 131. Relaxed sleeping posture, lying on back (A) and on side (B). C, poor posture. Note the neck flexed and the knees fully extended.

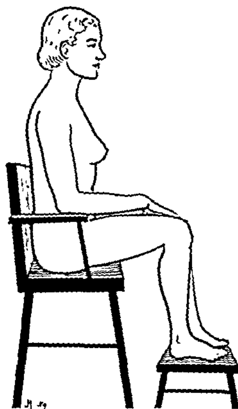
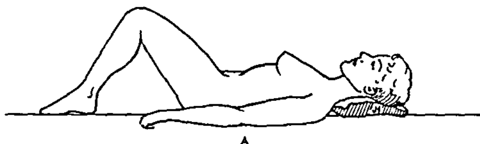


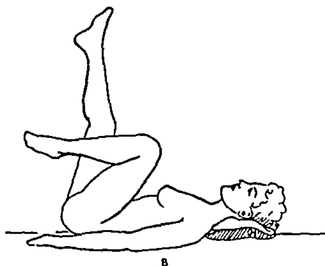
FIGURE 132. Correct sitting position. Knees should be on a slightly higher plane than the hip joints.

130). Attention to proper carriage, posture exercises and proper abdominal breathing are all important. Physical therapy, consisting of locally applied heat, preferably dry heat as an electric pad, followed by diathermy and gentle massage are sometimes of great benefit. Correct sleeping posture and elimination of bed sag by placing a fracture



A

FIGURE 130. A, position for diaphragmatic breathing. First slowly inhale, not using the intercostal muscles. Next exhale with a hissing sound by contracting the diaphragm muscles and tensing the abdominal muscles. Repeat this exercise 10 to 15 times, preferably while lying supine on a flat, hard surface.



B

B, position for the bicycle exercise. Flex knees and hips fully as shown; then simulate bicycle riding (25 to 30 revolutions) several times a day.

board between the mattress and the bedsprings are of value and give more relief than many other measures in these types of cases (Fig. 131). All foci of infection should be considered and their elimination advised.

Measuring the length of the lower extremities and correcting inequalities of leg length should always be done. Sitting correctly (Fig. 132) and not slumping in one's chair or using a soft unupholstered chair

for bed rest will be indicated, using 8 to 10 lbs. with a Buck's extension apparatus. Daily physical therapy, consisting of baking, diathermy and gentle massage, or sedatives may temporarily be required. Cautionary orders against heavy lifting or twisting the body for several months after leaving the hospital may prevent another acute attack.

Epidural injections of Novocain have been recommended, and Steindler (1938) has advised the injection of Novocain into the painful "trigger points" of the back.

Manipulation of the back under anesthesia is a method of treatment which, if used, should be done with great care and is rarely warranted. Sometimes stretching of the hamstring muscles and the application of a long plaster spica, allowing the patient to rest in bed from 4 to 6 weeks, may relieve certain patients with severe sciatic scoliosis and restore the normal contour to the back.

A search for foci of infection should not be neglected.

Operative treatment. In those cases of chronic muscle strain without roentgenographic evidence of disease or injury in which conservative treatment has failed, fusion of the lumbosacral or sacroiliac joint may be necessary, depending upon the joint involved. This is a valuable procedure but should be reserved for those cases in which conservative treatment over a reasonable length of time has not been successful. It must be remembered that a lumbosacral fusion means the posterior elements of the fifth lumbar vertebra are surgically fused to the sacrum, and that a sacroiliac joint fusion means the obliteration of all movement at this joint. Many different technics have been employed to attain surgical fusion, but the author prefers to use bone from the laminae and spinous processes for the fusion, augmented by autogenous cancellous and cortical iliac and tibial bone grafts packed about the area. Six to eight weeks after fusion the patient is allowed out of bed (some authorities prefer a shorter period of recumbency), but should wear a back support until there is definite evidence by roentgenogram of bony fusion at the site of operation.

FRACTURES OF THE VERTEBRAL COLUMN

Fractures of the vertebral column comprise over 6 per cent of all fractures throughout the skeleton, and their great importance lies in the fact that serious damage to the spinal cord may ensue. Traumatic lesions to the cord may be irreparable, but fortunately the cord often escapes serious damage.

will often prevent recurrence of backache. Heavy lifting (Fig. 133) should always be done by arm and knee bending rather than back bending. Adhesive back strapping as described in another chapter (p. 474), or the use of the old-fashioned cautery, which is touched lightly to the

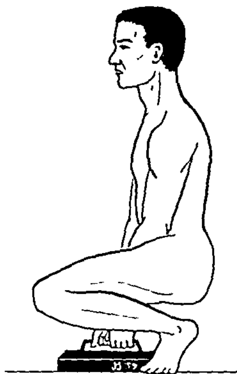


FIGURE 133. Correct way to lift a weight, which minimizes the strain to the back muscles.

back producing local counterirritation, should be resorted to occasionally. In all cases *of low back pain which seem to be of postural origin,* examination of the feet and correction of any abnormalities in walking as well as the use of proper shoes are advisable. Sometimes correction of the foot mechanics by a properly fitting arch and shoe with a wedge of ⅛ inch or ¼ inch on the inner border of the heel and sole will relieve the patient of backache after other conservative measures have failed. A properly fitting back brace may at times give decided relief (see Chapter 17, especially Figure 484).

If pain and muscle spasm are severe, these simple measures will not suffice. It then may be necessary to admit the patient to the hospital or have him placed on a firm mattress at home in a recumbent attitude and continue physical therapy in these surroundings. Colonic irrigation to eliminate poisonous intestinal stasis has its place in the treatment of low back pain In some instances, adhesive moleskin traction to the legs or pelvis after the patient has been admitted to the hospital

downward on a board or stretcher so that the spine is kept extended. The dangerous method of lifting a patient by the shoulders, allowing the spine to flex, and dragging the patient into the semisitting posture is to be vigorously condemned. Attention should be specifically directed toward transporting the patient quickly to a hospital and having both anteroposterior and lateral roentgenograms made at the earliest possible moment, i.e., as soon as the patient's general condition will permit.

Hospital care. If shock is present, morphine, warmth, intravenous saline-glucose and plasma or whole blood should be administered. As soon as the patient's condition justifies it, roentgenograms should be made. If possible these should be taken under the direction of the surgeon in order to avoid any unnecessary movement of the patient.

Patients without cord injury. The injured patient should be placed in bed in a supine position upon a Bradford frame and medication prescribed for local pain and abdominal distention. The adjustable convex Bradford frame is most useful and, unless shock contraindicates it, immediate steps for reduction should be instituted by making the frame slightly convex. The vertebral body fracture alone without dislocation is reduced by reversing the motion which produced it, that is, by hyperextension (Fig. 134). The Goldthwait type of adjustable frame is very useful, for it permits early application of a well-fitting plaster jacket in the overcorrected or hyperextended attitude. A general anesthetic is not necessary for muscle relaxation when this jacket is applied. To lessen the patient's apprehension, morphine and scopolamine are useful. If the fracture is acute, it may be necessary to place the patient on an adjustable frame for several days so that hyperextension may be gradually accomplished before applying a plaster jacket. As a rule, the problem of reduction in the lumbar region is very much easier and safer than in the dorsal region. Following reduction and before the application of the plaster jacket, a lateral roentgenogram should be made to check the position of the fracture. The plaster should be worn for 8 to 10 weeks. During that time, if the fracture compression has been in the low dorsal or lumbar region and if there is no evidence of injury to the cord, the patient may become ambulatory in the hyperextended position. A spinal brace can then be worn for the succeeding 4 to 6 months, but strenuous physical activity should be limited for 10 to 12 months after the fracture was sustained.

In certain vertebral dislocations, especially those in the dorsolumbar region, when closed reduction has failed an open reduction of the

Occurrence. It must be remembered that great violence is not necessary to produce a vertebral fracture, for relatively minor traumas are commonly responsible. Spinal fractures are most common in persons in the vigorous period of life between the third and fourth decade; at no age period is an individual exempt from this injury, although it is rare in childhood and adolescence. Fracture produced by a fall, severe jar or a sudden weight landing on the head and shoulders, flexing the body, would suggest the possibility of a compression fracture. Under these conditions the patients may not be completely disabled and in some cases may wish to return to their work, complaining only of a backache.

Fracture of the spine, whether involving a vertebral body alone or a portion of the posterior elements, should be divided into those with and those without *cord injury.* Fractures or dislocations of the dorsal and lumbar vertebrae are more common than those involving the cervical region. The history usually discloses that a force has been exerted to flex the spine and at the same time compress it longitudinally, so that actual damage to the viscera, muscles, intervertebral disks and ligaments often exceeds the damage appearing in the roentgenogram. The area at or near the dorsolumbar region is the most common site for fracture or dislocation.

Clinical Picture. Pain may be localized at the region of injury or referred along the corresponding peripheral nerve segments. Accompanying the pain, subsequent muscle spasm in the back and abdomen is usually severe. In this type of case there is some degree of surgical shock which must be combated at the earliest possible moment.

The range of motion of the spine should not be tested. Cord injury should be suspected when a partial or complete paralysis or paresis occurs below the level of the lesion Cases that are complicated by cord injury, of course, are more serious and give rise to many complications such as urinary or fecal incontinence and elevated temperature, with sometimes the development of peritonitis and/or pneumonia. In these severe cases, even if the patient survives with the best of nursing care, bedsores and skin sloughs upon the dependent parts may be unavoidable.

Treatment. *Emergency care.* In suspected spinal injuries first-aid treatment is of tremendous importance, for by judiciously handling the patient at the scene of the accident, damage to the spinal cord may be avoided or lessened. Any patient suspected of having an injury to the dorsal or lumbar spine following an accident should be rolled face

duce symptoms suggestive of a more severe cord injury than will later be found. The patient with a crushed or severed cord must be made as comfortable as possible and every attempt made to avoid development of bedsores and bladder infection. Incontinence of feces and urine may or may not be present, depending on the extent of the cord damage, but an ascending urinary infection is always to be feared and tidal drainage should be started early.

In addition to treating these patients *with spinal cord lesions* as outlined, a Forster bed may be used, or a plaster support to give complete rest to the extremities may be applied from the toes to the axilla, with the knees very slightly flexed and the feet in plaster at right angles to the legs, with a crossbar at the heels to prevent rotation at the hips. The plasters may be then bivalved, thus allowing half of the skin area to be exposed and gently massaged when the patient is turned daily. *The lower extremities should be carefully watched for* return of sensation and function. Urinary and fecal incontinence with secondary infection always makes the prognosis a grave one. The Rehabilitation Centers throughout the United States have been able to train many of these badly disabled patients to walk with braces and crutches and have greatly stimulated them to become self-supporting.

Old malunited fractures. In old healed unreduced fracture of the spine, where there is no paralysis but persistent pain, the roentgen films may indicate union of the fracture, but they will also show a definite deformity with angulation of the spinal column. Often a course of physical therapy, consisting of baking and massage, will give considerable relief to the patient. Sometimes, however, a solid bony union of the fracture is manifest but a traumatic arthritis has developed about the site of fracture. This may have developed because of an unsatisfactory reduction or an insufficient period of fixation.

Symptoms of pain and tenderness are aggravated by motions of the spine, and in these cases a spine fusion is usually indicated. In those patients showing cord or nerve root pressure months or years after the fracture, one must be aware that spicules of bone or an intervertebral disk injury may be producing pressure. This may be confirmed by myelogram, and a laminectomy may reveal evidence of pressure locally. The source of the pressure should be removed. Spine fusion may be performed at the same time. These are extremely specialized operations and should be attempted only by a surgeon trained in this type of work and in a fully equipped hospital. The prognosis is usually poor.

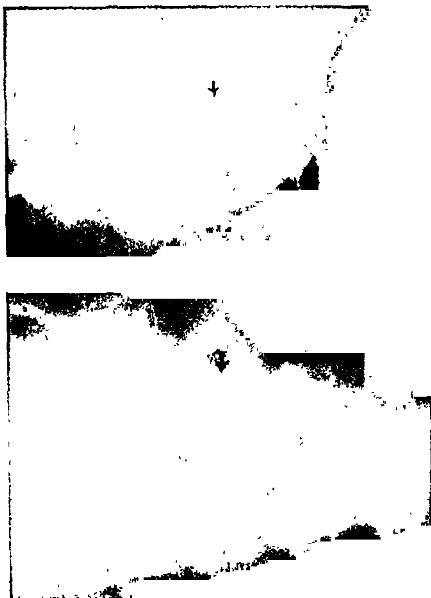


FIGURE 134 Compression fracture of vertebral body. *Upper,* with wedging; *lower,* correction by hyperextension of spine.

dislocated facets may be successful. Sometimes less trauma is caused by open reduction than by manipulation alone.

Patients with cord injury. If fracture of the spine is complicated by cord injury, the situation is far more serious. When paralysis is due to pressure on the cord by displaced bones, a closed reduction may relieve the symptoms; if it does not, an early laminectomy is advisable. If the cord has been completely severed or crushed, the prognosis becomes progressively worse. At the time of the original injury there is always considerable hemorrhage at the site of injury; this may pro-

duce symptoms suggestive of a more severe cord injury than will later be found. The patient with a crushed or severed cord must be made as comfortable as possible and every attempt made to avoid development of bedsores and bladder infection. Incontinence of feces and urine may or may not be present, depending on the extent of the cord damage, but an ascending urinary infection is always to be feared and tidal drainage should be started early.

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Cervical Region Injuries

In dislocation or dislocation-fracture of the upper first and second cervical vertebrae produced by severe trauma, such as diving into shallow water or falling from a tree, the head is usually tilted to one side and the chin turned to the opposite side. This injury is associated with considerable pain and limitation of motion. Although dislocation is the conspicuous feature, it is often accompanied by fracture, and an oblique roentgenogram must always be included for it may be the only view that reveals the fracture.

The so-called *whiplash* injury, frequently occurring in automobile collisions, particularly rear-end collisions, produces cervical spine and



FIGURE 135. Fracture-dislocation between the fifth and sixth cervical vertebrae.

associated structural injuries, the fourth, fifth and sixth cervical vertebrae (Fig. 135) being particularly prone to injury (Billig, 1953). The free, normal mobility of the neck permits varying degrees of injury and displacement to the bone or bones, to the intervertebral disks or to other adjacent soft tissues and causes a wide diversity of signs and symptoms. Before present-day safeguards, the catapult method of

launching planes from battleships saw frequent examples of whipping the head and neck backward or forward.

It must be remembered that the initial symptoms sometimes are minimal immediately following the injury. However, within 24 hours, the neck usually begins to stiffen, muscle spasm appears and a complaint of pain in the head, shoulders and upper extremities with sensory disturbances is common (Braaf and Rosner, 1955).

While clear roentgenograms may not be easy to obtain, one must make every effort to get anteroposterior, lateral and oblique views; especially helpful, if they can safely be obtained, are roentgenograms with the neck in flexion, neutral position and forced extension.

Treatment. Reduction of the fracture should be attempted as soon as possible. If at all feasible, it is preferable not to use a general anesthetic. The reduction is effected by a head halter, or preferably skeletal traction on the head, and by gentle manipulation, which reverses the motion through which the vertebrae passed at the time of injury. Care must be taken during the manipulation to avoid further damage to the spinal cord.

After reduction it may be necessary to continue skeletal traction for a few weeks, and, subsequently, a plaster collar is applied for 8 to 10 weeks. Following this, a leather or celluloid collar in the severe cases is worn for the next 6 months. The course of the patient will be the determining factor in deciding if and when spine fusion may be necessary.

Sometimes a complete or incomplete dislocation of the cervical vertebrae occurs without fracture. A spontaneous subluxation or even dislocation can occur, giving rise to wryneck and a great deal of pain on movement. Deformity and symptoms will usually disappear in these cases with adequate head traction and recumbency for a few days. Frequent bedside roentgenograms must be made — lateral, anteroposterior, and oblique views — for these will give evidence of the benefit obtained with the traction.

Fracture of the Odontoid

While many of the reported odontoid fracture cases were in association with fracture of the axis, P. Wurnig demonstrated that odontoid fracture could occur in the absence of injury to the atlas. Most of these fractures have resulted from severe violence, usually to the head but occasionally to the neck. It has even been reported as resulting from a children's fight. Amyes and Anders reported 63

cases and gave an excellent review of the literature, pointing out that in young children this fracture is always an epiphyseal separation. The fracture line in children is found well below the facets in the body of the bone; in the adult, this line occurs at the level of or above the upper articular facets. Solid bony healing, when it occurs, is usually rapid, but nonunion is common.

Any violence throwing the head into extreme flexion, extension or rotation may produce an odontoid fracture. There is usually immediate subluxation of the atlas on the axis, forward displacement of the odontoid being twice as common as backward displacement.

There are few signs or symptoms of severe pain, the most common being in the occipital region, and an accompanying fracture is frequently initially overlooked. Immediate severe damage to the cord or medulla oblongata may be a sudden cause of death; therefore, spinal cord damage should be sought. The backward displacement type is the more serious. Late paraplegia in the adult, arising within 12 months after injury, due to lack of bony union, has been reported; it even may occur many years later.

Treatment. The displaced odontoid should be reduced by traction under local anesthesia either by Crutchfield tongs, or by insertion of Kirshner wire through the outer table of the vault of the skull and held by a bow, the traction being in line with the longitudinal axis of the odontoid. Final treatment consists of immobilization by traction for 6 weeks followed by the use of a Minerva jacket for another 6 weeks.

Fracture of the Dorsal and Lumbar Vertebrae

A large percentage of all spinal fractures involve the twelfth dorsal and first and second lumbar vertebrae. These fractures are caused by longitudinal pressure combined with spinal flexion. The bodies are jammed together with continuing force, producing severe fracture and dislocation, often with disk injury; with displacement, the cord is damaged as well as the ligaments, and the capsular and muscular tissues.

Treatment. If the patient is seen at the scene of the accident, he must be kept recumbent but moved quickly, if possible, to a hospital where adequate measures to combat shock and fracture can be given.

At the hospital clear roentgenograms must be obtained with a minimal amount of spinal movement. A clinical examination along with a careful study of the roentgenograms should be done as soon as possible. The abdomen must be carefully palpated for any intra-abdominal pathologic condition and if this is negative, plans must be formulated

for reducing the fracture. Unless there are specific contraindications, hyperextension of the spine should be instituted early. Usually there is some abdominal distention that follows the accident, but within 24 hours this usually has definitely improved. During this interval an adjustable hyperextension frame or bed will allow the patient more comfort than the immediate application of a plaster jacket. Hyperextension should be done on a Goldthwaite frame or between two tables, and a plaster jacket applied within the first few days if there is no cord damage. This allows the patient to become ambulatory at a much earlier date; while no set plan of convalescence is applicable in all cases, early ambulation is desirable and hastens the convalescence. A brace can be exchanged for the plaster jacket in 10 or 12 weeks and is worn for 6 to 8 months after the original injury.

Kümmell's Disease

This disease was first described by Kümmell in 1895. It is a complication following fracture of the body of a vertebra, which may develop months after the spinal fracture (Blaine, 1930). In this condition the centrum or body of the vertebra becomes progressively more deformed long after the original injury. The deformity is apparently due to an avascular necrosis caused by a disturbance of circulation to the body of the vertebra. Some believe that it is caused by too early weight bearing without adequate fixation, resulting in a gradual crushing of the body of the vertebra. A continuation of spinal support over a sufficient period of time rarely results in complete bony regeneration and spine fusion may have to be done.

Fractures of the Transverse and Spinous Process

Fractures of the transverse process may be painful, but they are not usually serious. Sudden contraction of the quadratus lumborum muscle produces the indirect pull producing these injuries, but they may also be produced by direct injury such as a local blow. A fracture should be considered a dissolution of bony continuity plus associated soft tissue damage, and it is the latter component in these fractures that delays convalescence and gives rise to chronic persistent pain. Baking and gentle massage with later strapping of these back muscles hastens the cure.

In both these fractures, healing is usually uneventful and very rarely is excision necessary even if nonunion follows the injury. Treatment consists in strapping the back and limiting activity for the few weeks,

but exercises should be instituted as soon as possible, since they hasten the convalescence.

Fracture of the Ribs

Fractures of the ribs are usually due to direct violence. The usual site is from the midaxillary line forward. In childhood the ribs are so elastic that fracture of them is extremely rare.

Clinical Picture. The clinical features consist of pain on deep breathing, sneezing or coughing, and crepitus on deep inspiration. The linear bony tenderness may reveal the exact site of the fracture. In partial fractures there may be few symptoms, but if fracture is complete, crepitus may often be noted. If the palm of the examiner's hand is

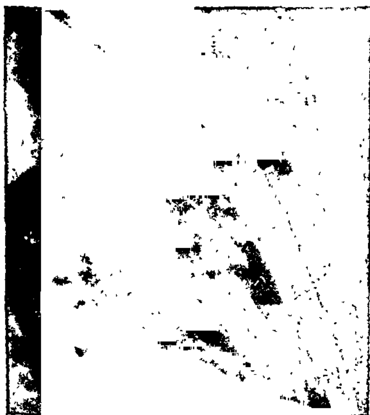


FIGURE 136. Rib fracture.

placed flat against the suspected area of the chest wall, a slight crunch or click may be felt on respiration. Movements of the patient are very guarded because of pain. A roentgenogram (Fig. 136) should be employed to confirm the diagnosis.

Treatment. This should be directed toward controlling the movements of the chest so as to relieve the pain. If one rib is broken a most

satisfactory treatment consists in immobilizing the chest wall by a 2 or 3 inch adhesive strapping swath going two-thirds around the chest. This should be applied during periods of expiration. If the injury is more severe, rest in bed with heat applied locally will be more satisfactory.

Simple fractures of the ribs usually unite promptly. Complications and sequelae of fractured ribs, however, should be sought for and kept in mind during the examination as occasionally an injury to the pleura or lungs may occur. Its existence may become manifest by bloody expectoration or emphysema. The complications should be treated symptomatically.

Injuries to the Sternum

Fractures and dislocations of the sternum are unusual because of the strong protection offered the bone by the mobility and elasticity of the chest wall. When they do occur they are due to direct violence. The usual location is near the junction of the first and second portions of the sternum which can be felt as a definite ridge opposite the second costal cartilage. Since severe injury is necessary to produce a fracture of the sternum, other associated lesions are likely.

Treatment. If there is no displacement, prompt recovery is the rule. Spontaneous reduction of the dislocation has been reported in several instances from coughing or sneezing. A small sandbag placed between the patient's shoulders while he lies in a recumbent position usually suffices to reduce the dislocation. Following reduction, immobilization with adhesive plaster for 3 to 4 weeks with the patient resting in bed will usually effect a cure.

Injuries to the Intervertebral Disks

The work of Schmorl (1928), Mixter and Barr (1934) and others has centered attention upon the possibility that certain cases of back pain are dependent upon injuries to the intervertebral disks. Over 95 per cent of these injuries are found in the lumbar region between the fourth and fifth lumbar and the fifth lumbar and the first sacral vertebrae.

The normal disk consists of a central portion (the nucleus pulposus), which is a semifluid medium under pressure, and a peripheral portion (the annulus fibrosus), which forms a fibrocartilaginous capsule about the nucleus pulposus. Two thin plates of hyaline cartilage separate

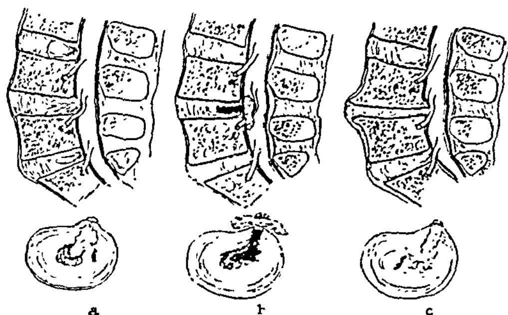


FIGURE 137. Three common types of herniations: *a*, simple reducible herniation with intact capsule; *b*, complete extrusion of sequestrum through ruptured point capsule; *c*, advanced type with narrowing of disk, bony proliferation, and fibrosis involving nerve root. (Duncan, W., and Hoen, T. I. *Surg. Gynec. & Obst.*, 75:257, 1942.)

the disk from the thin layer of compact bone on the superior and inferior surfaces of the vertebral bodies (Fig. 137).

The *degenerated changes found with increasing age sometimes* are responsible for a break in the cartilage plate that protects the nucleus pulposus; this material may find its way into the vertebral bodies, above and below, giving rise to certain characteristic herniations that have been known as Schmorl's nodules. Schmorl (1928) found this type of prolapse in 38 per cent of the spines examined at autopsy. Although these nodules appear to be a rather common finding in autopsy studies, there is reason to believe that they account for certain cases of backache. Usually, when the nodules protrude into the body of the adjacent vertebra above or below, they present few symptoms.

Clinical Symptoms. In addition to these protrusions into the adjacent vertebral bodies above and below, the herniation may also be forced backward into the spinal canal. When the prolapse of the nucleus material ruptures or protrudes *posteriorly,* it is in close proximity to the spinal cord and the nerve roots; it gives symptoms of direct pressure with intractable pain radiating down the posterior thigh and into the calf and foot, accompanied by sensory disturbances, frequent loss of ankle jerk, with or without low back pain

It must be remembered that the signs and symptoms may be almost

identical with those of many other conditions causing backache and only by careful examination may an exact diagnosis be made and the disk proved to be the offending agent.

Although a comparatively small percentage of cases having backache and referred pain down one or both lower extremities can be said to be due wholly to a protruded nucleus pulposus, certainly in many cases it becomes necessary to rule out this syndrome. The history of a sudden onset, at which time the spine is actively or passively flexed or twisted, is often obtained. Recurring attacks are common and the two pain components of low backache and sciatic pain may or may not coexist; the radiculitis or referred sciatic pain is the more constant (Fig. 138).

It is to be remembered that low back pain with sciatic distribution,

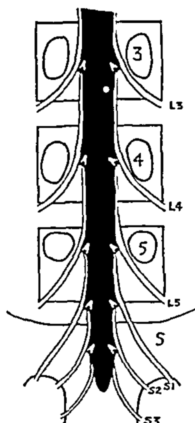


FIGURE 138. Relation of the thecal sac and lower lumbar and sacral nerves to the pedicles and intervertebral disks of the lower spine. The area usually filled by lipiodol is black. It is limited laterally by the successive nerve roots. The subarachnoid space extends beneath each root as it enters its dural sleeve, forming the axillary pouch (A). The fifth lumbar nerve is contained within the dural sac opposite the fourth lumbar disk, but the first sacral nerve enters its dural sleeve above the lumbosacral disk. (After Hampton and Robinson, from Bradford and Spurling, *The Intervertebral Disc*. C. C. Thomas.)

if accompanied by muscle spasm and atrophy, loss of ankle reflex, and sensory distribution which point to the disk between the fourth and fifth lumbar and the fifth lumbar and first sacral vertebrae, frequently demands no further data to substantiate the diagnosis. However, even this textbook picture of a protruded or ruptured disk may be combined with a long-standing low back instability on a postural or skeletal basis which demands adequate correction. Correction can consist of external immobilization, such as an adequate belt or brace, or internal immobilization, such as a fusion at the site of instability even after removal of the protruded or ruptured disk.



FIGURE 139 Pantopaque injection illustrating defect indicative of protrusion of the intervertebral disk between the fifth lumbar and first sacral vertebrae.

Many cases do not present such clear-cut evidence of disk pressure symptoms as just cited so that clinical examination alone is insufficient and a myelogram becomes necessary to make the diagnosis.

The usual roentgenogram will show no evidence of this protrusion, although a narrowed joint space might suggest its presence. A lumbar puncture may show the total protein content of the spinal fluid to be

between 45 and 200 mg., which is suggestive, but other conditions also cause this elevation.

Treatment. Preferably, an opaque substance such as pantopaque or Diadrast is injected into the spinal canal to determine whether there is a projecting mass of disk tissue causing pressure on the cord or nerve roots (Fig. 139). Not all cases of proven disk protrusion require removal of the disk. About 30 per cent of cases with positive myelogram can be made symptom-free by the tried conservative methods of bed rest, traction to the affected limb, physical therapy, and the fitting of adequate back support when weight bearing is resumed (Colonna and Freidenberg, 1949).

Operative removal of the disk should, in the author's opinion, be reserved for patients not obtaining relief of their sciatic pain following a regimen of conservative care.

Coccygodynia

Coccygodynia, or pain in the region of the coccyx, may be due to injury or disease of the coccyx or of the pelvic organs, or the development of a sacrococcygeal bursitis. If the pain is a result of injury, frequently the history is given of "sitting down hard suddenly."

Diagnosis. The diagnosis is not difficult to make. Roentgenograms may or may not show a deviation of the coccyx. A rectal examination will usually disclose increased mobility with some angulation as well as pain on attempted movements of the coccyx between the examiner's index finger and his thumb. In some of the cases a bursitis apparently develops at the sacrococcygeal joint. These acute bursitis cases without displacement usually respond to radiation treatment alone.

Treatment. In treating the patient with acute coccygodynia with displacement of the coccyx, the coccyx should be gently manipulated into its approximately normal position and then the gluteal folds tightly strapped together with wide adhesive plaster strips. The patient is instructed to sit on an air ring cushion or squarely upon a hard-bottomed chair. As hard fecal material sometimes aggravates the condition, it is advisable to give the patient small doses of mineral oil for a few weeks.

Another method of treatment is the injection of procaine hydrochloride in and about the coccyx. This frequently gives relief.

If all these measures fail, operation with removal of the coccyx should be employed, but only as a last resort. A certain proportion of these patients show neurotic tendencies, so that operation and removal of the coccyx is not initially recommended.

CONGENITAL DEFORMITIES

Congenital anomalies of the spine are very common; in fact, it has been estimated that not more than one person out of five has a completely normal vertebral column. Absence or failure of ossification centers or accessory centers of ossification produces anomalies of many varieties.

Congenital anomalies or malformations of the spine or ribs may assume various patterns. For example, there may be a hemivertebra; a lack of fusion of the neural arch, unilateral or bilateral; an extra vertebra (Fig. 140) or absence of the normal number may be observed, a sagittal or butterfly cleft may occur; or the bones may appear scrambled and distorted in the cervical region, the patient presenting a thick weblike neck with mirror movement of the upper extremities (the Klippel-Feil syndrome). The articular facets may be set at different planes from the normal (asymmetrical facets), and this at times renders the patient more susceptible to back injuries than the average



FIGURE 140. Six lumbar vertebrae, an infrequent congenital anomaly.

individual. Associated with these may be other congenital anomalies elsewhere in the body.

Klippel-Feil Syndrome

This is a congenital synostosis of the cervical vertebrae which are misshapen and scrambled together. There is a notable loss in length of the neck, with the head appearing to sit down on the shoulders, as well as a webbed appearance on either side of the neck due to the prominence of the bone and soft tissue deformity. Rarely is it accompanied by any nerve root irritation. There is limitation of neck movement and roentgenologically there may be other congenital bony anomalies present besides the cervical vertebral ankylosis. The short neck, the low hair line, the webbed appearance to the neck and the roentgenic findings are all characteristic features (Fig. 141).



FIGURE 141. Klippel-Feil syndrome. Note webbed appearance and almost complete absence of neck contour.

There has been at least one case reported (Furst and Ostrum, 1942) in which platybasia, Sprengel's deformity and Klippel-Feil syndrome occurred in the same patient, suggesting that there may be a connecting link in the formation of these three rare congenital anomalies. It is important to differentiate this syndrome from congenital torticollis.

Treatment. No treatment is indicated other than plastic surgery for cosmetic reasons.

Cervical Rib

Cervical ribs are not uncommon, usually affecting the seventh cervical vertebra. They may be unilateral or bilateral, and may exist with or without signs of nerve irritation. They may be suspected in patients with an unusually wide base at the neck and are of surgical interest because they occasionally produce pressure on the nerves and blood vessels as they pass in close relation to the first rib. This may give rise to an ache or tingling in the whole arm and even paresis of the whole upper extremity. Symptoms do not usually appear until late adolescence or early adult life, at which time vascular changes may give rise to pallor, coldness or cyanosis of the hands and fingers due to pressure on the affected sympathetic nerve fibers about the lower part of the brachial plexus. There may be increasing weakness and pain in the hand and inability to carry out the finer movements. The extra rib may be palpable in the supraclavicular region; if not, roentgenograms (Fig. 142) will prove its presence.



FIGURE 142. Bilateral cervical ribs.

Differential Diagnosis. Because of its symptoms, a cervical rib may be confused with syringomyelia, progressive muscular atrophy, lesions of the ulnar nerve, or even an unusually long transverse process. In some instances the train of symptoms may arise from the restricting band of the scalenus anticus muscle in the so-called scalenus anticus syndrome or in a patient with cervical arthritis. However, 55 per cent of cervical ribs are found accidentally and are symptomless.

Treatment. Conservative methods of treatment may not prove successful and excision of the rib or section of the transverse band of the scalenus anticus muscle is then necessary to relieve the condition. Excision of a cervical rib is a difficult and tedious operation but sometimes is necessary. The anterior approach is the method of choice in these cases.

Scalenus Anticus Syndrome

Murphy (1905, 1906) first drew attention to the scalenus anticus muscle and tendon as a factor in producing symptoms similar to those produced by cervical ribs. This condition is characterized by spasm or hypertrophy of the scalenus anticus muscle, producing compression on the brachial plexus and subclavian artery. The scalenus anticus tendon is inserted into the first rib, separating the subclavian artery and vein, and aids in producing symptoms closely resembling those of cervical ribs. Pain is always present, primarily between the shoulder joint and elbow, but often also in the supraclavicular fossa directly over the first rib. Numbness and tingling of the little and ring fingers are usually noted first. Numbness, muscle weakness, pain and tenderness are confined roughly to the distribution of the ulnar nerve. If the arm is in the dependent position, the pulse in severe cases may be barely perceptible in the wrist, and in at last one-fourth of the cases there has been noted a marked difference in the blood pressure on the two sides. An occupational basis may be the cause for the development of some of the cases, and poor posture with sagging of the shoulder girdle would seem to be a factor in others. Cervical arthritis will also very closely simulate the symptoms of this condition.

Treatment. This may be conservative or operative. Elevation of the arm over the head will give temporary relief in many cases. Procaine infiltration of the muscle has been reported effective. If these conservative methods fail, the scalenus tendon should be exposed and divided. The operation is not a difficult one but must be done very

meticulously because of the close proximity of the subclavian vein, artery and brachial plexus.

Congenital Torticollis

Congenital torticollis may be unilateral or bilateral. If unilateral, the head is deviated toward the affected side and the chin is rotated toward the opposite shoulder, giving rise to the so-called wryneck position (Fig. 143). There are *two types* of congenital torticollis. In the

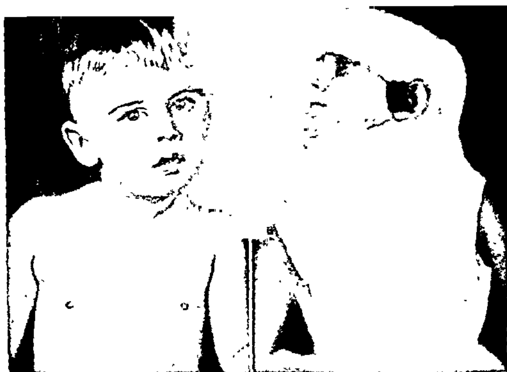


FIGURE 143. Right congenital torticollis (*left*) with head tilted to right and chin to left. Note the slight but definite facial asymmetry. *Right*, overcorrected position of head held in plaster after tenotomy of contracted muscles and fascia.

simpler and more common type, the wryneck is caused by soft tissue contraction involving the sternocleidomastoid muscle and its sheath and sometimes the platysma muscle. In the other type, it is caused by some underlying congenital anomaly of one or more of the cervical vertebrae. Both types are believed to be congenital in origin, but because of the pudgy neck of infants, the wryneck is not usually noted by the parent until the deformity has persisted for several months or longer. The contracture is painless and is accompanied by definite facial asymmetry which increases as the child grows older. In the ado-

lescent child, secondary deformities such as cervical scoliosis may appear in the trunk, and upward bowing of the clavicle caused by the tension of the contracted muscles may be seen at times.

Hematoma caused by injury at birth is visible as a hard, fusiform swelling in the sternocleidomastoid muscle and may be responsible for a few cases of so-called congenital torticollis, but the great majority of the cases with only soft tissue contraction arise from malposition in the uterus. Labor may be difficult and cause the formation of a hematoma post-partum but this labor difficulty is caused by the malposition in the uterus.

Differential Diagnosis. In young children in whom examination is sometimes difficult, this condition may be mistaken for enlarged cervical lymph glands, otitis media or cervical Pott's disease, all of which can be ruled out by a careful examination.

Occasionally a definite wryneck attitude will develop in cases of eye muscle imbalance. These patients usually do not show any soft tissue contractures unless they have been neglected for a long time. After proper eye care has been instituted the torticollis deformity usually disappears.

Treatment. If the patient is seen within the first six months of life, in the majority of cases with the simple type of soft tissue congenital torticollis daily methodical stretching of the head and neck in the overcorrected attitude will usually be sufficient to obtain correction of the deformity. The mother can be instructed how to stretch the contracted soft tissues. Chandler advises excision of the tumor-like mass found in the sternocleidomastoid muscle in many of these infants (Chandler and Altenberg, 1944). In older children open tenotomy, usually at the insertion of the affected sternocleidomastoid muscle, permits the head to be brought into the overcorrected position (Fig. 143). It is then held in this position in a plaster cast or other form of support from 5 to 6 weeks, after which time exercises and physical therapy permit full correction of the wryneck. In the second type of case in which there is an underlying congenital anomaly of one or more cervical vertebrae, one can only hope to obtain a proportionate amount of correction. If treatment in the first type is instituted early, usually the secondary deformities of facial asymmetry, cervical scoliosis and eye strain from optical imbalance will disappear. However, in the adolescent or adult absolute correction can never be obtained, but definite cosmetic improvement can be achieved.

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simpler and more common type, the wryneck is caused by soft tissue contraction involving the sternocleidomastoid muscle and its sheath and sometimes the platysma muscle. In the other type, it is caused by some underlying congenital anomaly of one or more of the cervical vertebrae. Both types are believed to be congenital in origin, but because of the pudgy neck of infants, the wryneck is not usually noted by the parent until the deformity has persisted for several months or longer. The contracture is painless and is accompanied by definite facial asymmetry which increases as the child grows older. In the ado-

lescent child, secondary deformities such as cervical scoliosis may appear in the trunk, and upward bowing of the clavicle caused by the tension of the contracted muscles may be seen at times.

Hematoma caused by injury at birth is visible as a hard, fusiform swelling in the sternocleidomastoid muscle and may be responsible for a few cases of so-called congenital torticollis, but the great majority of the cases with only soft tissue contraction arise from malposition in the uterus. Labor may be difficult and cause the formation of a hematoma post-partum but this labor difficulty is caused by the malposition in the uterus.

Differential Diagnosis. In young children in whom examination is sometimes difficult, this condition may be mistaken for enlarged cervical lymph glands, otitis media or cervical Pott's disease, all of which can be ruled out by a careful examination.

Occasionally a definite wryneck attitude will develop in cases of eye muscle imbalance. These patients usually do not show any soft tissue contractures unless they have been neglected for a long time. After proper eye care has been instituted the torticollis deformity usually disappears.

Treatment. If the patient is seen within the first six months of life, in the majority of cases with the simple type of soft tissue congenital torticollis daily methodical stretching of the head and neck in the overcorrected attitude will usually be sufficient to obtain correction of the deformity. The mother can be instructed how to stretch the contracted soft tissues. Chandler advises excision of the tumor-like mass found in the sternocleidomastoid muscle in many of these infants (Chandler and Altenberg, 1944). In older children open tenotomy, usually at the insertion of the affected sternocleidomastoid muscle, permits the head to be brought into the overcorrected position (Fig. 143). It is then held in this position in a plaster cast or other form of support from 5 to 6 weeks, after which time exercises and physical therapy permit full correction of the wryneck. In the second type of case in which there is an underlying congenital anomaly of one or more cervical vertebrae, one can only hope to obtain a proportionate amount of correction. If treatment in the first type is instituted early, usually the secondary deformities of facial asymmetry, cervical scoliosis and eye strain from optical imbalance will disappear. However, in the adolescent or adult absolute correction can never be obtained, but definite cosmetic improvement can be achieved.

Spondylolisthesis

The ordinary form of spondylolisthesis is caused by a congenital nonunion of the pars interarticularis (neural arch) of one of the vertebrae (Fig. 144). It practically always occurs in the lumbar region, most frequently the fifth lumbar vertebra, but it has been reported in other regions of the spine. Probably 95 per cent of malpositions occur between the fourth and fifth lumbar or the fifth lumbar and first sacral



FIGURE 144. "Doggie sign" for third lumbar vertebra. The fifth lumbar vertebra shows characteristic defect in the neural arch found in spondylolisthesis.

vertebrae (Fig. 145). Nonunion without displacement is thought to be present in at least 5 per cent of all normal individuals, and in some of these individuals the condition of so-called "prespondylolisthesis" or "spondylolisthesis" is present. It is probable that some cases are of

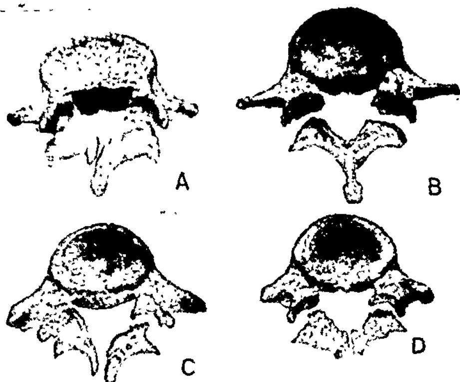


FIGURE 145. Neural arch anomalies in lower lumbar vertebrae. *A*, spina bifida occulta. *B*, bilateral defect between the superior and inferior articular facets. *C*, unilateral lamina defect combined with spina bifida. *D*, bilateral defect combined with bifida and undeveloped spinous process. (From Willis, Theodore A. *J. Bone & Joint Surg.*, 14:267–277.)

acquired origin, the theory being that a cartilaginous fracture of the neural arch may occur in the descent of the infant during its birth. The symptoms of spondylolisthesis may be induced by trauma or stress and strain produced by the upright attitude.

When the affection occurs at the fifth lumbar vertebra, forward displacement of the body of the fifth lumbar vertebra on the sacrum may be slight or severe. At times a complete forward dislocation of the fifth lumbar vertebra may occur. The condition was first described by Killian in 1854 and it has received particular attention within the past few years because of its medicolegal importance. In many of these patients the roentgenograms will show a definite displacement following an injury received when lifting, or from some similar strain, and this may be the first evidence of back trouble; however, most authorities believe that the displacement has existed for many years, and this mechanical weakness has simply made the back more susceptible to injury than the normal spine.

Pathology. The inferior interarticular facets of the normal vertebra prevent it from moving forward, but if there is a defect in the neural

arch of the laminae or pedicles the portion of the vertebra anterior to the defect will have no bony check to prevent the vertebra from slipping downward and forward. The reverse of the typical spondylolisthesis, that is, a posterior displacement of the fifth lumbar vertebra upon the sacrum, has been described, but its causation has not been convincingly explained. It is believed that spondylolisthesis in general is a congenital lesion, although cases are reported in which it appears probable that the fracture may have been through the cartilage of the neural arch at the time of birth, so that the lesion in these cases may be considered acquired and of traumatic origin. The lumbosacral region is an area in which a flexible column meets a fixed base or pelvic ring and is subjected to tremendous stresses and strains, and this would most readily favor forward and downward displacement at this point.

Clinical Picture. Pain in the low back, increased lordosis and stiffness of the back which becomes worse after exercise or strain are all familiar features of this condition. Occasionally the contour of the back is flat, but usually a prominent and sharp ridge can be felt, which is the upper border of the sacrum, and a deep hollow noted at the site of displacement (Fig. 146). Restriction of the spine on forward bending is often present. With signs and symptoms of weakness and discomfort in the lumbar region, pain running down the posterior surface of the



FIGURE 146. Spondylolisthesis Characteristic body attitude and deep furrow at lumbosacral junction *Right*, severe forward displacement of column at lumbosacral joint.

thigh, and a prominence of the spinous processes of the sacrum with a corresponding depression immediately above it as well as extreme tenderness on pressure over the spinous processes, spondylolisthsis is a likely diagnosis. Lateral and oblique roentgenograms should always be made to confirm this. In 207 cases studied by the author, 76 per cent were between 30 and 50 years of age before presenting themselves for study.

Differential Diagnosis. It may be difficult without a roentgenogram to differentiate spondylolisthesis from Pott's disease in the lumbosacral region, lumbosacral strain, or any lumbosacral disease or injury. The increased lordosis and awkward gait sometimes seen may be confused with that due to a bilateral congenital dislocation of the hip, although by careful palpation for the dislocated heads of the femurs such a mistake should be avoided.

Lateral and oblique roentgenograms are most informative. They will show the neural arch defect and the forward slipping of the body of one of the vertebra on the other, so that half or more of the body of the fifth lumbar vertebra may be protruding over the sacrum, giving the appearance of a very unstable and precarious state. Careful spot roentgen films should be made of the suspected areas and search should be made for the nonunion of the neural arch which is usually in the lamina or pedicle portion of the vertebra.

Treatment. Prespondylolisthesis is the term that has been applied to those cases in which there is roentgenographic evidence of nonunion of a portion of the neural arch without demonstrable slipping, and in these cases conservative measures consisting of a properly fitting back support may relieve the patient of whatever symptoms of stress and strain he may have. In the cases with slight or moderate slipping, body exercises to lessen the lordosis and an adequate back brace should be tried; these may relieve the symptoms.

In cases with severe actual displacement as demonstrated by roentgen studies, any conservative treatment directed toward reducing dislocation fails. Generally the slipping is of long standing and although it may become worse under stress, strain or trauma, the deformity does not lend itself to closed reduction. In these cases the most satisfactory method of treatment is *spine fusion.* About 15 per cent will require spine fusion (Whitman, 1932). When the fifth lumbar vertebra is displaced forward, operative fixation of the fourth and fifth lumbar vertebrae to the sacrum is indicated. The Hibbs' type of fusion, reinforced by a graft from the adjacent ilium or from the tibia, offers the best

opportunity for solid bony fusion. Following operation, the patient should be recumbent for from 8 to 10 weeks and then remain in a snugly fitting brace from 6 months to a year following the operation. This type of operation results in surprisingly little restriction to the movements of the spine.

There are various types of rare malformations, such as congenital absence of the various muscles of the back and chest wall. It must be remembered that other congenital anomalies may be combined with underlying skeletal anomalies and that there may be isolated malformation of parts or groups of soft tissues.

Spina Bifida

Lack of fusion in the midline of one or several neural arches gives rise to a congenital gap in the posterior portion of the vertebral column through which a hernial protrusion of the sac derived from the dura



FIGURE 147 Infant with spina bifida and meningocele.

mater protrudes. This condition is known as spina bifida. In the meningocele type, cerebrospinal fluid but no nerve tissue fills the sac, whereas in the myelocele type a cleft leads from the skin surface into the interior of the spinal canal (Fig. 147). Many cases show skeletal

defects without protrusion of the contents of the spinal canal, the so-called "spina bifida occulta" (see Fig. 145A). It is in spina bifida that clawfoot deformities are occasionally an associated finding. The tumor or sac is situated in the midline and may vary in size. In defects of the spinal column demonstrable by roentgenograms, the occulta type is the most common and least disabling type of spina bifida. However, cases have been reported of paralysis with gradual onset that would appear to be associated with spina bifida occulta. This may be because the growth of the spinal column is more rapid than that of the cord, and the fibrous adhesions found at this area may aid in impeding the normal ascent of the cord, causing compression of the nerve roots.

Slight degrees of spina bifida occulta are frequently seen in normal adults and may play a part in certain cases of low back pain for the reason that these spines are more liable to the stress and strain of physical activity. In the true spina bifida, injection of oxygen into the sac may give valuable aid in determining the distribution of the nerve structures in the back before operation is performed, but treatment belongs to the field of neurosurgery. In spina bifida, operation is sometimes indicated and should be done when signs of pressure develop in later childhood.

If there is an extradural lipoma, which occasionally occurs, it may have to be excised, including the fibrous bands which connect the dura to the skin.

Sacralization

Sacralization of the fifth lumbar vertebra occasionally occurs. In this condition one or both of the transverse processes of the fifth vertebra are greatly enlarged and may impinge upon the sacrum (Fig. 148). Unless careful roentgenograms are made, however, the apparent impinging of the enlarged transverse process upon the sacrum is misleading.

Treatment. Back support, combined with physical therapy and eradication of any focal infection, will usually relieve the local pain. Only in the rare instances when a definite arthritis is present at this point of pressure should operative removal be necessary.

Sprengel's Deformity

Sprengel's deformity is a congenital elevation of the scapula. It is sometimes designated "undescended scapula." Usually the deformity is unilateral with some impairment of arm function due to limitation

of scapular movement. The affected scapula is smaller than its fellow and has less mobility on the chest wall. In 20 to 30 per cent of the cases there is an osseous or ligamentous connection between the scapula and spine. These patients may have other congenital defects which should



FIGURE 148. Bilateral sacralization. This congenital anomaly is also accompanied by a lack of lamina fusion.

be looked for in all cases. When a bony bridge extends from one of the cervical vertebrae to the scapula it is given the name of an omovertebral bone.

Treatment. Improvement can be achieved in the milder cases by running fascial strips from the scapula to vertebrae or the crest of ilium (Spira and Axer, 1947), and by holding the bone nearer its normal position after loosening the bone from its muscle attachments and performing an osteotomy on the clavicle. In the severe cases, which are often complicated by other congenital anomalies of the ribs, surgery can offer little improvement.

Platybasia

Platybasia is described as a rare congenital deformity of the occipital bone and upper portion of the cervical spine. The diagnosis is deter-

mined by the amount of the odontoid process projecting cephalad to Chamberlain's line (Chamberlain, 1939) (Fig. 149). Roentgen films should consist of lateral and frontovertex exposures. The affection may be recognized at any age and in more than 80 per cent of the cases



FIGURE 149. Platyblasia; note Chamberlain's line.

diagnosis has been made on roentgenographic and not on clinical findings. In those few cases with signs of compression of the cervical vertebrae and more widespread involvement somewhat resembling multiple sclerosis, decompression has been the treatment of choice. In over one-fourth of the cases other congenital anomalies of the cervical vertebrae other than the basilar invagination have been found (Moreton, 1943).

Cleidocranial Dysostosis

Cleidocranial dysostosis is a partial or complete congenital absence of one or both clavicles, usually the latter. Jansen (1921) believes there is a general stunting of growth produced by abnormal infolding of the amnion at the eighth week of embryonic life. It is a rare condition affecting both sexes about equally, and the condition is usually accompanied by defects related to the cranial bones, such as imperfectly developed frontal bones and delayed closure of the fontanels. There is an abnormally high palate and the teeth may be delayed, irregular or absent.

It may not be noticed on casual inspection; the most striking feature

of scapular movement. The affected scapula is smaller than its fellow and has less mobility on the chest wall. In 20 to 30 per cent of the cases there is an osseous or ligamentous connection between the scapula and spine. These patients may have other congenital defects which should



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It may not be noticed on casual inspection; the most striking feature

is demonstrated when the shoulders are forced toward one another. Without clavicular rigidity the shoulders can be brought together under the chin.

Treatment. Rarely is there much disability. Surgical treatment is only indicated when a nubbin of the clavicle causes mechanical discomfort; it may then be removed.

Diastematomyelia (Diplomyelia)

Duplication of the spinal cord has been given various names and may occur in varying degrees. About 50 cases of this rare condition have been reported in the literature (Neuhauser; Herren and Edwards, 1940; Maxwell and Bucy, 1946; Pickels, 1949). In some of the instances there is a true duplication of the cord and more than half of the instances were associated with a spina bifida occulta, with widening of the interpedicular spaces of the affected vertebrae.

Clinical Picture. There are no specific clinical features found to be common in all of the cases and there are usually other congenital anomalies noted in the bony structure of the spine. The most common associated deformity is clubfoot. The myelogram, using pantopaque, has been found of some value in making a preoperative diagnosis. Usually there is a projection of bone impinging upon the dura and its contents, or the cord is split and divided at the site of the bony projection. This stellate-like spur can be sometimes noticed on a flat plate in the anteroposterior view of the spine and almost always occurs below the sixth dorsal vertebra. Only about one-fourth of the cases were found in adolescence or adult life, most of the reported cases being in infants.

Treatment. Excision of the bony spur has been done in a few cases with improvement but the decision as to surgery should be made in the individual case, depending on the local congenital defects of the bone and soft tissues.

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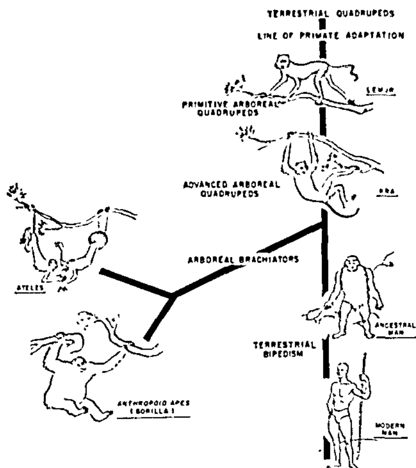
4

The Shoulder

According to a relatively modern functional theory advanced by G. S. Miller, the distinctive human line branched off from the generalized primate stock at a point near that at which the line leading to the gorilla and chimpanzee originated. In the illustration of this theory (Fig. 150) the lemur (Tarsius) is taken as an example of a primitive arboreal quadruped; the Old World monkey (Kra) is a more advanced type of arboreal quadruped, while the New World monkey (Ateles) is a true brachiator. The Old World monkey characteristically maintains his head erect; he never hangs by his hind legs nor uses his tail for locomotion. The New World monkey, a brachiator, often hangs by his hind legs and also possesses a prehensile tail.

A comparative study of the osteology and myology of the lemur, Old World monkey and man shows interesting changes in the configuration of the chest, which has become flattened and widened transversely. This allows man to place his arm both in front of and behind his body. A greater purchase of the long rotators is thereby obtained. The scapula, in its development through the lemur and monkey, has become longer and wider, reaching its greatest extent in man. As a result, the short rotators have greater purchase, thus increasing their rotatory potential The flattening and widening of the thorax also has produced a change in the position of the scapula. In the lemur, the scapula is near the lateral aspect of the chest, but in the Old World monkey and in man, it has moved posteriorly.

As a consequence of the changes in the thorax and in the position of the scapula, the humeral head has changed. In the lemur, the glenoid



	SCAPULA	THORAX	INFLUENCE OF EVOLUTIONARY TORSION UPON THE TUBEROSITIES	EVOLUTIONARY TURNING OF HUMERAL HEAD FROM MILLER R.A AM JOURN PHYS ANTHROPOLOGY p 56 LEFT HUMERUS
LEMUR	INCREASED LENGTH OVER EARLIER MAMMALS	WIDENS IN COMPARISON WITH EARLIER MAMMALS	TUBERCLES OF EQUAL SIZE AND BICIPITAL GROOVE LIES BETWEEN	A B C D; A B AXIS OF HEAD & NECK C D TRANSV AXIS EPICOND
OLD WORLD MONKEY (KRA)	INCREASES IN CEPHALO-CAUDAD DIRECTION	CONTINUES TO WIDEN	BICIPITAL GROOVE MOVES MEDIALLY	
MAN	CONTINUES TO LENGTHEN	GREATEST WIDTH	THE LESSER TUBERCLE BECOMES SMALLER AS THE GROOVE MOVES MEDIALLY	

FIGURE 150. *Upper*, evolution of man. *Lower*, evolutionary changes of the shoulder.

cavity faces almost directly anteriorly. In the monkey, the glenoid cavity looks more laterally. In man, this lateral facing is even more pronounced. In order to maintain its functional relation with the glenoid cavity, the humeral shaft has undergone torsion, but the position of the humeral condyles has remained the same. Because of the torsion of the humerus, the bicipital groove encroaches upon the lesser tuberosity and, according to Inman and his associates (1944), causes the tuberosity to become smaller.

In the evolutionary development through the lemur and Old World monkey the short rotator muscles, with the exception of the supraspinatus, have all increased in size and have reached their greatest volume in man. It is believed that the supraspinatus muscle has become smaller because there is no longer the functional need for muscular power overhead. In the lemur, the deltoid muscle is divided into two parts, the spinous and the acromial, with the latter inserting more distally. In the more advanced forms, the deltoid is one muscle. In man, the deltoid muscle has three parts, but they are combined in one distinct muscle. The pectoralis major is combined with the pectoralis minor in a common pectoral muscle that inserts onto the humerus, in the lemur. A pectoralis abdominis muscle is also present. In the Old World monkey, the pectoralis major and the pectoralis minor are separate muscles; the pectoralis minor inserts onto the humerus. The pectoralis abdominis is still present. In man, the pectoralis major and the pectoralis minor are distinct muscles; the insertion of the pectoralis minor has moved to the coracoid process and the pectoralis abdominis muscle has disappeared.

That "ontogeny repeats phylogeny" is seen in embryonic development of the shoulder. In a 9-mm. embryo, the pectoralis minor and the pectoralis major muscles are combined in a "common pectoral mass" and insert onto the arm. In the 11-mm. embryo, the pectoralis minor has begun to dilineate as a separate muscle and is moving toward the coracoid process.

While these changes are occurring in the pectoral muscle mass, the entire arm bud is undergoing external rotation. At the same time, torsion is progressing at the upper end of the humerus. It is important to recall here the correlation between the external rotation of the limb bud and the internal torsion of the humerus. The rotation of the limb bud in the embryo consists of turning 90 degrees in a lateral direction. The torsion represents the difference in the relative position of the long axis of the proximal and distal ends of the bone and takes place al-

most entirely at the upper end of the humerus. The primary or inherited internal torsion, which is seen in an embryo of 20 weeks, amounts to approximately 42 degrees. There is relatively rapid change in the degree of torsion throughout the remainder of embryonic life, so that at birth it has reached approximately 65 degrees. Torsion continues until puberty, but at a greatly decreased rate, and reaches a maximum of approximately 74 degrees at the end of the growth period.

APPLIED ANATOMY

Active movement of the arm in abduction will reveal what Codman (1934) has designated the "scapulohumeral rhythm" (Fig. 151). This

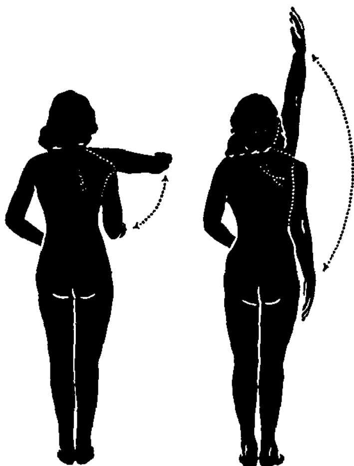


FIGURE 151. Scapulohumeral rhythm. The scapula begins rotating during initiation of arm abduction movement.

is a complex process, consisting not only of movement of the shoulder joint proper between the head of the humerus and the glenoid cavity, but also of movement of the scapula on the thoracic wall and move-

cavity faces almost directly anteriorly. In the monkey, the glenoid cavity looks more laterally. In man, this lateral facing is even more pronounced. In order to maintain its functional relation with the glenoid cavity, the humeral shaft has undergone torsion, but the position of the humeral condyles has remained the same. Because of the torsion of the humerus, the bicipital groove encroaches upon the lesser tuberosity and, according to Inman and his associates (1944), causes the tuberosity to become smaller.

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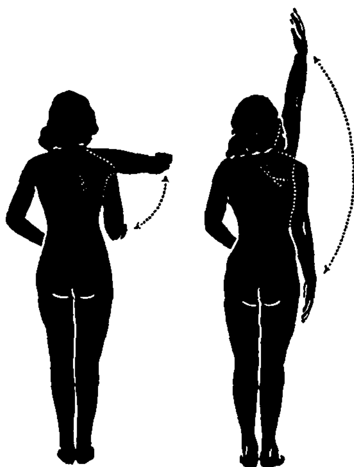


FIGURE 151. Scapulohumeral rhythm. The scapula begins rotating during initiation of arm abduction movement.

is a complex process, consisting not only of movement of the shoulder joint proper between the head of the humerus and the glenoid cavity, but also of movement of the scapula on the thoracic wall and move-

ment at the sternoclavicular and acromioclavicular joints. Each of these movements is not entirely separate. The scapula rises and rotates on the chest wall very early in the maneuver of abduction. This scapulohumeral movement is a rather complicated one. Each of the shoulder movements is interrelated and integrated, together comprising the "unit of motion." Disturbance to one of these parts invariably has some effect on the remaining portion of the unit of motion.

Construction of both upper and lower extremities is similar. The scapula corresponds to the ilium, the coracoid process to the ischium, and the clavicle to the pubic bone (Jackson, 1923). In each limb there are four segments: the shoulder girdle corresponds to the pelvic girdle, the arm to thigh, the forearm to the leg, and the hand to the foot. All have undergone modifications during their evolution, depending on the different functions required.

The Shoulder Girdle. The shoulder girdle consists of the scapula and the clavicle, and these bones are supported in two ways: (1) directly, by the suspension of muscles attached to the head and neck vertebrae; and (2) indirectly, by the sternum and ribs in the manner of a yoke extending above the rib cage. A mechanical balance between *these forces is essential to good function and good posture, for when* the shoulder girdle is out of balance the muscles are put under undue drag, giving rise to muscle strains and muscle tensions. From this alone, pain and ache in the shoulder region will develop. This yoke must be carefully balanced by the ligaments and muscles so that the weight of the shoulder does not drag upon and depress the first rib, producing neurogenic or circulatory disturbances.

A considerable portion of the weight of the upper extremity is transferred to the head by strong muscles running from the scapula and clavicle to the mandible and the mastoid and styloid processes, as well as by the strong posterior group of cervical muscles attached to the vertebrae and occipital portion of the skull. With the shoulder girdle balanced, the tip of the acromion should be in the same plane and in line with the lobes of the ears when the arms are hanging at the sides.

Elevation of the scapula is due to the action of the levator scapulae and the upper portion of the trapezius muscles; depression of the scapula is caused by the action of the pectoralis minor and serratus anterior muscles. Codman (1934) feels that this scapulohumeral rhythm is so constant and simultaneous with abduction of the arm that he makes the statement, "if the scapula were nailed to the chest wall the arm could not be moved 45 degrees from the abducted position,"

Ordinarily, in complete elevation of the arm 60 degrees of abduction occurs at the scapulothoracic articulation and not more than 120 degrees at the glenohumeral joint.

The muscles which act on the scapula are (1) the trapezius, which rotates the scapula, and the levator anguli scapulae muscle, which directly elevates the scapula; (2) the serratus magnus or anterior, which is the antagonist of the trapezius, its action being to draw the scapula against the chest wall downward and forward; (3) the rhomboids, which draw the scapula toward the spine; and (4) the pectoralis minor, which is the antagonist of the rhomboids, drawing the scapula forward. In addition, when the humerus is fixed, the muscles which run from the humerus to the scapula can move this latter bone.

In the shoulder joint proper, the bones consist of the upper extremity of the humerus, with its rounded head, its short anatomic neck and its two tuberosities, and the shallow glenoid socket of the scapula, supported by its neck and overhung by the acromion process above and protected by the coracoid process anteriorly. The shoulder joint depends almost entirely upon its strong muscles and ligaments for security and very little upon its osseous conformation.

The muscles that cross the humeroscapular joint are in two layers. The superficial layer of muscles (consisting of the pectoralis major, latissimus dorsi, deltoid, and teres major) may be considered as the prime movers of the shoulder joint, whereas the deeper layer of muscles (composed of the subscapularis, supraspinatus, infraspinatus and teres minor) may be considered as the stabilizers and rotators of the joint. From the functional standpoint, the pectoralis major and latissimus dorsi are primarily adductors, flexors and extensors of the humerus, and have, under conditions of normal function, a rotary effect at the shoulder joint. The deltoid is a forceful abductor of the humerus, but in addition, the anterior fibers are strong internal rotators and the posterior fibers are strong external rotators. The teres major is an adductor, backward extensor and internal rotator, depending on the position of the arm.

Of the deeper group of muscles, the subscapularis is a powerful internal rotator and adductor of the humerus and also serves as a strong anterior buttress to the shoulder joint. The rotator cuff muscles, i.e., the supraspinatus, the infraspinatus and the teres minor, are strong external rotators of the joint and also stabilizers working in conjunction with the superficial prime movers. In the earlier primates, the pectoralis minor also served as an internal rotator of the humerus, but

in man, owing to the transference of its insertion from the humerus to the coracoid process, it no longer acts on the humerus. (It is interesting, nevertheless, that in 1 per cent of 1000 shoulders examined by Seib (1938), this muscle was found to cross the shoulder joint with *attachment to the humerus.)*

The shoulder joint is of the ball-and-socket variety. The shallowness of the glenoid cavity allows this joint a greater variety and extent of movement than any other joint in the body, and evolution of the shoulder has been in the direction of increased mobility (at the expense of some stability). Like all enarthrodial joints, the shoulder is capable of the four basic movements (flexion, extension, adduction and abduction) as well as rotation and a combination of these movements, that is, circumduction.

When the humerus is abducted as far as a right angle, the greater trochanter lies under the arch of the acromion. In further elevation of the arm the accompanying rotation of the scapula on the thoracic wall (see Fig. 151) as well as the movement at the sternoclavicular and acromioclavicular joints become marked. Most authorities state that abduction is initiated by the supraspinatus muscle and continued by the deltoid muscle. Adduction is accomplished by the latissimus dorsi and the pectoralis major, teres major and subscapularis muscles; flexion by the coracobrachialis muscle and anterior fibers of the deltoid and pectoralis major muscles; internal rotation by the subscapularis, latissimus dorsi, teres major and pectoralis major muscles; and external rotation by the teres minor and infraspinatus muscles. Many of the muscles producing motion at the shoulder are fan-shaped and have a compound action. For example, the lateral portion of the deltoid muscle along with the supraspinatus abducts the arm proper, but true adduction is prevented by the arm coming in contact with the chest wall. The flexion-adduction movement is produced by the pectoralis major and the latissimus dorsi muscles. Pure flexion is produced by the anterior portion of the deltoid and the coracobrachialis muscle. Extension is produced by the posterior part of the deltoid and the scapular head of the triceps along with the teres major.

The relation of the long head of the biceps to the shoulder is important. It is attached to the upper margin of the glenoid cavity where it blends with the glenoid ligament (Fig. 152). It is a powerful agent in retaining the head of the humerus in close approximation with the glenoid cavity. The shoulder joint capsule is remarkably well reinforced by ligaments and protected by a cushion of muscles, forming

Clavicula
Lig. acromioclaviculare
M. supraspinatus
Acromion
Bursa subacromialis
Capsula articularis
M. biceps brachii (caput longum)
M. deltoideus
Epiphysis proximalis
Cavitas glenoidalis scapulae

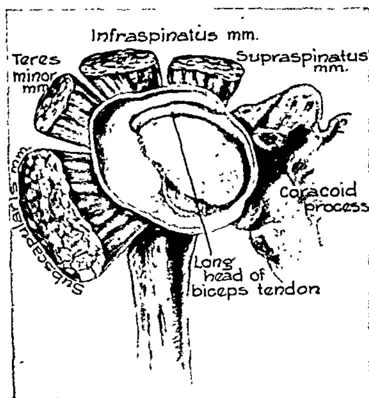


FIGURE 152. *Upper,* frontal section through the shoulder region (Callander, *Surgical Anatomy*). *Lower,* capsule of shoulder and its muscle attachments.

the so-called musculotendinous cuff. This consists essentially of the tendons of the supraspinatus, infraspinatus, teres minor and subscapularis muscles, which fuse with the articular capsule of the shoulder joint, forming a continuous envelope encasing the head of the humerus. The first three tendons insert in their respective facets on the greater tuberosity, and the last on the lesser tuberosity of the humerus. The weakness of the cuff inferiorly makes this region sometimes susceptible to dislocation of the humeral head into the subcoracoid position. Tears, both complete or incomplete, of the tendinous cuff, particularly of and near the insertion of the supraspinatus tendon, are common injuries.

The synovial membrane of the shoulder joint is extensive. It lines the interior of the capsule and is reflected over the margin of the anterior surfaces. A prolongation of this membrane continues over the long tendon of the biceps for a short distance in the bicipital groove, and tenosynovitis of this tendon is *one* of the causes of "frozen shoulder."

The large subdeltoid bursa is in a vulnerable position for injury, but as a rule does not communicate with the shoulder joint. The subdeltoid bursa is in constant use with all motions of the shoulder and its normal condition is indispensable for normal joint function. It has been compared to a joint without articular cartilage.

The bursa beneath the subscapularis and the one beneath the infraspinatus often communicate with the shoulder joint. The subscapularis bursa is the more important, and is present in three-fourths of shoulders. The opening from the joint into this bursa is represented on the bone by the notch in the anterosuperior portion of the glenoid rim. The bursa lies on the upper edge of the subscapularis muscle as well as on a strip of its ventral and dorsal surface. In half the cases in which it is present it does not communicate with the joint; in the other half it connects between the superior and middle glenohumeral ligaments. If the middle glenohumeral ligament is absent, the bursal opening may reach the upper border of the inferior glenohumeral ligament.

When the shoulder joint motion is restricted by fibrous adhesions, the motions which are lost are particularly those of rotation and abduction of the humerus, so that the hand cannot be placed behind the back or head or the arm elevated. With this condition, however, the excellent rotary motion of the scapula on the chest wall may enable the patient to mask his loss of normal function in the shoulder joint remarkably well. To formulate a satisfactory prognosis in shoulder joint disease, it is necessary to have information regarding joint surfaces and bursae,

and also regarding the degree of involvement of the synovial membrane and muscular soft tissue in the shoulder region.

Acromioclavicular Joint. This joint owes its stability not only to the joint ligaments but also in great part to the strong conoid and trapezoid ligaments running from the clavicle to the coracoid process of the scapula, the so-called coracoclavicular ligaments.

Sternoclavicular Joint. This joint has a definite meniscus and is firmly protected by its strong ligaments, which make dislocation at this point rare, although anterior dislocation sometimes occurs. The range of motion at the sternoclavicular joint when the arm is elevated is considerable, and any surgical procedure resulting in arthrodesis to this joint should be avoided if possible.

Epiphyses of the Shoulder Region. These epiphyses are not visible by roentgenogram until some ossification has occurred (Fig. 153).

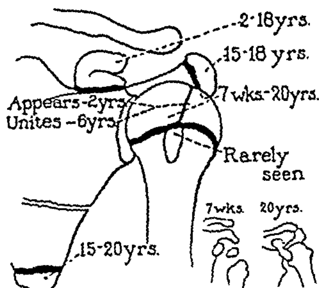


FIGURE 153. Ages at which appearance and fusion of the epiphyses of the shoulder region occur.

While there is a possibility that the greater tuberosity develops from a separate epiphysis, Cohn (1924) believes there is only one definite epiphysis for the upper end of the humerus and that the greater tuberosity is a downward overgrowth from the head of the humerus, whose ossification is evident about seven weeks after birth. The lesser tuberosity is rarely a separate epiphysis. The glenoid cavity, the acromion process (but not its epiphysis) and the clavicle are ossified to the same degree as the diaphysis of the humerus, while the coracoid epiphysis becomes evident about the second year. By the nineteenth to twentieth year all epiphyses about the shoulder have fused.

EXAMINATION

A careful physical examination must usually be the method of proving the existence of a disability involving the soft tissues of the shoulder region. Roentgenograms are of little help except in a negative way, unless evidences of calcification, dislocation, fracture or bone disease are present. *Mobility of the shoulder joint proper can be judged accurately only when the scapula is fixed.* This can be done by holding one hand firmly over the top of the shoulder during active and passive movements of the arm. It is obvious that disability in this region may become not an isolated entity but a very complex matter, making an anatomic diagnosis of certain injuries difficult. At times, it may be impossible to say that the lesion is confined to only one structure or that it is purely traumatic or infectious in origin. The effect of gravity, causing a drag on the shoulder mechanism, can also be a real factor in production of pain at the shoulder. Therefore, poor posture may be regarded as a definite factor in causing certain shoulder disabilities.

Formerly, the general term "periarthritis" was applied to all soft tissue injuries at the shoulder region, and this indefinite classification served to differentiate the condition from primary articular lesions. Currently, a more careful analysis is made in an effort to determine the underlying cause of the difficulty. Although the general symptoms of injury or disease in their early stages may be very similar, they differ in certain details.

Following a soft tissue injury to the shoulder, the patient generally complains of severe pain of a dragging character, aggravated when the arm is dependent. At first movement is restricted by muscle spasm, later, by contractures that may develop from the dependent position. Pain extends down the arm, chiefly on the outer side toward the insertion of the deltoid, or it may run up into the neck along the border of the trapezius. The patient voluntarily protects the shoulder by holding the arm against the side or supporting the elbow with the opposite hand. Muscular atrophy is usually obvious early and is sometimes so extensive that it may become a serious complication in subsequent functional restoration of the part.

The history of an injury makes it mandatory to rule out the more serious types of bone and joint disability. The shoulder must be inspected carefully to observe its contour. Deformity, tenderness and limitation of motion, which may follow any fall, must be searched for

in order to rule out dislocation at the sternoclavicular, acromioclavicular or shoulder joint, or fracture in the shoulder region.

Infection may present a gross deformity suggestive of dislocation or the patient may protect his arm in such a way that it suggests muscle injury. General constitutional symptoms combined with local heat,



FIGURE 154. Lateral view of humerus. This is made by not moving injured arm and by having the sound arm placed on the head and the film is then taken through the chest wall (Fletcher position). It may reveal fracture or epiphyseal slipping which would not be apparent in routine views.

redness and tenderness usually make the presence of an infectious process easy to determine. On palpation the normal landmarks can usually be identified, unless the shoulder is extremely swollen, and a decision can be reached regarding their position. The joints should be examined for evidences of injury to the bones and soft parts by passively moving the arm and by having the patient try to flex, extend, abduct, adduct and rotate the arm against resistance. Ability or inability to perform these movements gives valuable clues as to the site of the difficulty. With a definite individual muscle strain, pain will be aggravated when the arm is actively moved or passively stretched, pain being referred to the affected muscle either at its origin or insertion.

If certain muscle fibers have been ruptured, there will be acute local point tenderness.

Roentgenograms of the shoulder are sometimes puzzling; for this reason, views should be taken at different angles to avoid mistakes in diagnosis. An anteroposterior view is inadequate to obtain maximal information from roentgenographic studies. A lateral view (Fig. 154)



FIGURE 155. Osteoarthritis of the cervical vertebrae. An oblique view, as shown, may be especially informative, revealing arthritic encroachment on intervertebral foramina and between vertebral bodies.

through the chest with the uninvolved arm elevated and out of the way is usually satisfactory. If the arm can be safely abducted to a right angle, the picture can be made with the tube over the shoulder. In the case of the stiff shoulder in which rotation of the arm is limited, rotation of the patient and not of the shoulder may suffice to ascertain desired information concerning the joint abnormality. Internal and external rotation, steroscopic views, or, at times, examination of the joint in motion by means of fluoroscopy may all yield valuable information.

In all cases of referred pain to the shoulder, the cervical spine should be investigated for arthritic changes and/or injury to the cervical intervertebral disks (Fig. 155).

DISEASES

Tuberculosis of the Shoulder

Tuberculosis is much less common in the upper extremities than in the lower, weight-bearing joints. This fact strengthens the impression that the stresses and strains of weight bearing are a definite predisposing factor in the development of joint tuberculosis. Involvement of the shoulder joint accounts for less than 2 per cent of all tuberculous joints. Males are more often affected than females, and the right shoulder more often than the left. The disease is most frequent during the first two decades of life; it is rare in early childhood.

Pathology. Tuberculosis of the shoulder joint usually begins in the neighborhood of the bicipital groove (Fig. 156). The most frequent



FIGURE 156. Tuberculosis of the shoulder originating in the metaphysis of the humerus.

type is "caries sicca," so-called because the process is not accompanied by abscess formation. Destruction of the subchondral area of the bone usually occurs late. The whole articular cartilage may be undermined and lie practically loose within the joint. The disease may occasionally arise in the glenoid region of the scapula and usually begins in osseous tissue, although tuberculosis has been reported arising primarily from the synovial membrane.

Clinical Picture. Because impairment of motion at the shoulder joint proper may be so easily masked by movement of the scapula on the chest wall, marked limitation of motion is less obvious at this joint than in others.

The symptoms of joint tuberculosis are pain, sensitiveness, restriction of motion and muscular atrophy. The history of the chronic progressive disability may begin with a dull ache about the joint without known cause. This should arouse suspicion that the process is tuberculous until presence of the disease is either confirmed or excluded. Tuberculin tests and roentgenographic studies are valuable diagnostic aids. The caries sicca type of infection gives rise to a flattening of the shoulder which, if severe, may be mistaken for a coracoid dislocation of the head of the humerus. If there is abscess formation, aspiration and guinea pig inoculation are carried out to confirm the presence of acid-fast bacilli.

Treatment. Tuberculosis is always a generalized disease and involvement of the shoulder or any other joint is a local manifestation. During the past decade, medical treatment of tuberculosis of all types has been completely revolutionized by chemotherapeutic agents, isoniazid, PAS and streptomycin. These are used in various regimens, in which one, two or all three drugs are administered. These drugs have not obviated the need for surgical treatment in tuberculosis involving the bones, but they have made surgical success more feasible. Smith (1955), in a recently reported series, noted particularly the striking effects of both streptomycin and the isonicotinic acid derivatives on abscesses and sinuses. Synovial tuberculosis has been treated successfully without surgery. Dougherty and Sherman (1955) reported one such case of tuberculous synovitis of the shoulder in a 4-year-old boy, who received daily doses of 1 Gm. of dihydrostreptomycin intramuscularly and 6 Gm. of PAS orally for three and a half months. Four years after discontinuation of treatment the shoulder was painless, motion was normal and roentgenograms revealed healing of the lesion.

Nonsurgical ankylosis of the shoulder joint in optimal position for

functional use rarely occurs. The best position for rest is accomplished by placing the shoulder in a plaster spica at right-angled abduction and slightly anterior to the plane of the body, i.e., in the "salute position." In children, if surgery is delayed, a 90-degree abduction of the vertebral scapular border and the shaft of the humerus is advisable; and in adults, a 75-degree abduction is necessary. As a rule, conservative treatment should not be expected to result in a natural ankylosis.

Surgical fusion is not resorted to until the patient is at least 8 years old. Tuberculous tissue is excised and the raw bony surfaces of the humerus and glenoid cavity are apposed. There are various types of shoulder fusion (Campbell, 1956), but the operation described by Gill (1940) is simple to perform and mechanically effective.

It consists of splitting the acromion process and greater tuberosity of the humerus and fitting these together after denuding the articular cartilage from the humerus and glenoid fossa and closely approximating these surfaces. Immobilization by internal (such as a temporary Steinmann pin) and external fixation must be assured until the raw bony surfaces are fused. When the fusion operation is finished, the arm is placed in a plaster spica in abduction of 45 to 55 degrees to the vertebral border of the scapula, 15 to 25 degrees forward flexion, and 15 to 25 degrees internal rotation. The tremendous leverage that the upper extremity exerts at the shoulder always necessitates a long period of fixation.

Roentgenograms are the best available means of information as to whether or not ankylosis is solid. This union will require several months, and until it occurs, adequate support should be continued. If extensive destruction of bone has occurred after beginning treatment, the chances for bony ankylosis are poor. In tuberculosis of the shoulder joint, pulmonary complications are not unusual, and the death rate is higher than for tuberculosis in the joints of the lower extremity.

Acute Osteomyelitis

Acute osteomyelitis of the shoulder is now extremely rare; the upper end of the humerus is affected much less frequently than the large bones of the lower extremities. If the disease develops at its usual site, the metaphysis of the bone, it often spreads into the shoulder joint, because the metaphyseal area is intracapsular. For this reason, pyarthrosis is a common complication in osteomyelitis of the proximal end of the humerus. *Staphylococcus aureus* is preponderantly the causative organism; most other cases are streptococcic infections, although

other organisms are sometimes found. The source of infection in the metaphysis is usually hematogenous, the portals of entry being by way of the ears, throat, or any break in skin continuity caused by injury or infection (see Chapter 2).

The symptoms of local pain, sensitiveness and swelling, with constitutional evidences of toxicity such as fever, dehydration and leukocytosis, all give the characteristic picture of an acute inflammatory reaction. At times, however, differentiation from rheumatic fever, generalized septicemia, suppurative arthritis, poliomyelitis, bone tumor and cellulitis may be difficult in the early stages. Positive roentgenographic signs develop usually in 3 to 17 days.

Treatment. In acute osteomyelitis, use of conservative surgery must be combined with adequate drainage if a frank abscess is present. When osteomyelitis is suspected, vigorous antibiotic treatment should be administered. Large doses of penicillin are used in streptococcic osteomyelitis; usually a combination of antibacterial agents is used in staphylococcic infections. At the end of 3 weeks, if reontgenograms remain normal and clinical signs and symptoms have been absent for at least a week, it is probably safe to discontinue antibiotic treatment. Transfusions, infusions and general and local rest are also employed as indicated. The optimal position for immobilization of the arm is the salute attitude.

Chronic Osteomyelitis

In chronic osteomyelitis of the upper end of the humerus complicated by joint involvement or joint-cartilage destruction, some joint stiffness will result. Therefore, early immobilization in a plaster spica in the best functional position is desirable. In chronic osteomyelitis the Orr treatment is the method of choice. This consists of removing the dead bone, packing the wound with petroleum gauze and allowing it to heal from the bottom, while using one of the antibiotics systemically. Fortunately, complete ankylosis at the shoulder joint, provided the arm is in the position of election, will give very satisfactory function to the upper extremity because of the free mobility of the scapula on the chest wall.

SOFT TISSUE INJURIES

The muscles about the shoulder joint most frequently injured are the supraspinatus, biceps, deltoid, subscapularis, and to a lesser extent the pectoralis major, in the order named. In the movement of abduction,

the first action is contraction of the deltoid which presses the humerus up against the acromion, while the supraspinatus muscle has the principal function of initiating actual abduction. After an injury produced by a blow over the lateral surface of the shoulder, pain on attempted abduction may cause limitation to movement. The examiner should keep in mind the possibility of some injury to the bones, to the rotator or musculotendinous cuff, such as a tear of the supraspinatus tendon, or to the development of a bursitis, especially involving the subdeltoid bursa. With a rupture of the supraspinatus tendon the initiation of abduction is painful; however, further abduction may be accomplished easily with comparatively little pain. Elevation of the arm beyond the right angle is accomplished largely by the scapulothoracic muscle group.

The musculotendinous cuff or "rotator cuff" surrounding the shoulder joint is composed of the joint capsule, which is strengthened by the muscle fibers of the supraspinatus, infraspinatus, teres minor and subscapularis; these fibers merge into the tendinous cuff.

Suspraspinatus injuries are most frequent, being complete or incomplete tears near the insertion of this muscle into the greater tuberosity of the humerus. As the supraspinatus muscle forms a portion of the floor of the subdeltoid bursa, injury to this muscle results in adhesions between the roof and floor of the bursa (Bosworth, 1940; McLaughlin, 1945).

In all shoulder disabilities roentgenograms or flouroscopic views must be made routinely in several positions. Pain and the aching sensation may also be caused by disease, fracture of the humerus, scapula or clavicle, cervical arthritis, a cervical rib, or by the scalenus anticus syndrome. The two latter conditions may cause pressure symptoms on the brachial plexus or subclavian artery or vein. Excision of the extra rib or division of the scalenus anticus tendon near its insertion at the first rib may be necessary to relieve these two conditions.

Early in the treatment of all shoulder disabilities, the prevention of contractures is of prime importance. Therefore, rest and support on an abduction splint are advisable, for these measures not only bring about relaxation of the abductor muscle groups but also aid in preventing capsular contractures. As the term "frozen shoulder" is not in any way a diagnosis but simply a description, one must attempt to reach a diagnosis of the underlying pathologic condition. Occasionally underlying bone disease may cause the shoulder to be fixed to the side. If roentgenograms show no evidence of bone injury or disease, it must be assumed that the pathologic process lies in the soft tissues. In the

milder cases, rest in bed, increasing abduction and external rotation by continuous traction, combined with daily baking and massage to the muscles about the shoulder, will restore free motion. In the more resistant cases, full anesthesia and a gentle manipulation through the full range of motion may be advisable, followed by a subsequent period of baking, diathermy and massage. In the acute stage, roentgen radiation may at times give considerable relief.

Relaxed circumduction is a valuable method of safely initiating early motion following shoulder injuries. This is done by instructing the patient to bend forward at the waist while the upper extremity forms small increasing circles of circumduction motion (Fig. 157). The shoulder region thereby can obtain early motion to a considerable degree with the minimum amount of effort.

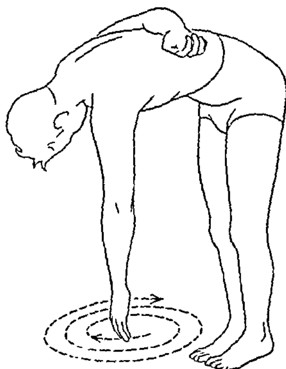


FIGURE 157. Circumduction exercises. These are helpful in mobilizing a stiff shoulder.

Supraspinatus Tears

In a suspected tear of the supraspinatus tendon, the patient is requested to lower the arm slowly. If the rupture of the tendon is complete, it will be noted that the arm can be lowered painlessly to a right angle or a little more and will then suddenly fall to the side with the accompaniment of localized tenderness near the insertion of the torn

tendon. If, as usually happens, the rupture of this tendon is only partial, this picture of sudden disability on lowering the arm is less dramatic and sometimes may even be accomplished with comparatively little discomfort. Thorndyke (1938) concludes from his study of a large group of athletes that most of the so-called incomplete ruptures are really mild muscle strains which will recover rapidly with daily diathermy and massage.

Injury to the supraspinatus tendon (Fig. 158) is a possibility in all cases in which the injury was received with the arm in abduction.

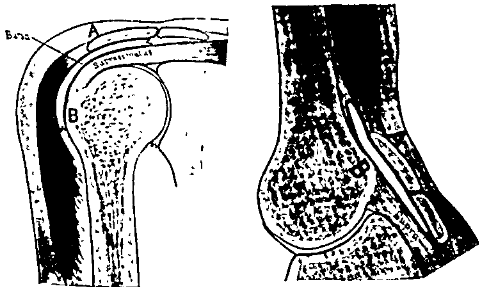


FIGURE 158. Forced elevation of the arm may pinch the subdeltoid bursa, producing bursitis, or it may injure the supraspinatus tendon by a partial or complete tear.

Evidence has been found of fraying of the tendon in a large percentage of autopsy subjects, indicating that not only acute traumas but the wear and tear of active daily life cause certain attritional changes in the tendon.

Treatment. In early treatment of complete tears, open operation, suturing of the torn cuff to the tuberosity, and support of the extremity in an attitude of abduction should be done. In acute cases with incomplete rupture open operation is not usually indicated. Support of the arm in the abducted position, followed by diathermy, massage and local application of heat, will suffice in the majority of the cases, although the return to normal function may be gradual. It is believed that patients with clinical evidence of complete tearing of the supraspinatus tendon, if operated upon early, should have a complete return of function of the part; however, the symptoms should be rather pro-

nounced to persuade one to operate upon an incompletely torn supraspinatus.

The severe type is most apt to occur in the laboring man over 40, without symptoms in the shoulder prior to accident, and with a history of an immediate sharp pain following definite injury. This pain can be localized by firm pressure over the insertion of the supraspinatus tendon. The roentgenogram usually shows no evidence of underlying pathologic change in the bone.

Calcified deposits may be demonstrated by roentgenogram both in the supraspinatus tendon (Fig. 159) and in the subdeltoid bursa and



FIGURE 159 Calcification in the supraspinatus tendon.

far less frequently in the infraspinatus and subscapularis areas. Doubtless these masses predispose these shoulders to episodes of acute pain, limitation of motion and severe disability. Frequently the calcifications are, however, noted in symptomless shoulders.

Tears of the Long Head of the Biceps

Of the other muscle tears about the shoulder, one should mention injury to the long head of the biceps. Localized tenderness in the

bicipital groove with swelling and soft crepitus in this region suggested this injury. The pain is aggravated by active movement of the biceps against resistance; sometimes the belly of the muscle can be observed bunched in the middle of the arm (see p. 286) and diastasis of the tendon can be palpated. Early open operation and the repair of the long head is necessary for return of function.

Bursitis

From a practical standpoint, the only bursa that can be clearly and clinically delineated in an acute bursitis at the shoulder is the subdeltoid or subacromial bursa. This lies beneath the deltoid muscle and under the acromion, separating it from the joint; it is about the size of a silver dollar. It sends prolongations to meet the acromion process and the coracoid ligaments; when distended it presents a mechanical obstacle to abduction.

The patient with acute bursitis is very sensitive to pressure over the tip of the shoulder and resists all movement in the direction of abduction. Occasionally swelling is obvious on the anterior aspect of the joint. Pain is most severe and the patient avoids lying on the affected shoulder at night; he complains of pain radiating up into the neck and down the arm, and the slightest movement of the arm causes excruciating pain. Although normally the roof of the bursa may be as thin or thinner than the peritoneum, it becomes much thicker when acute or chronic inflammation is present. In addition to isolated inflammation from injury or from infection, this bursa may become inflamed from chronic weakening or acute partial rupture of the underlying supraspinatus tendon. A subdeltoid bursitis, initiated by trauma, often may have some underlying tendon degeneration as a predisposing element. Calcified material, when present, originates not in the bursa, but in the tendon forming the floor of the bursa. This calcified material can be demonstrated roentgenographically and the changes it undergoes can be traced by serial films, which show that perforation of the toothpaste-like semicalcified deposits into the bursa occur (Fig. 160). According to Codman (1934), this discharge of the calcified mass into the bursa is Nature's way of attempting to cure the condition.

Treatment. In cases of acute bursitis, roentgen irradiation in small doses may give dramatic relief. For this reason, some surgeons recommend this procedure as the first step in treatment of acute bursitis of the shoulder. Besides its effect in relieving acute pain, roentgen irradiation also influences absorption of calcium deposits. When roentgen

irradiation is not used, or fails to provide relief, needling of the bursa reduces tension and gives almost immediate relief of pain. Relief by

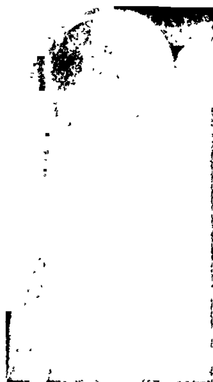


FIGURE 160. Calcification in the subdeltoid bursa.

aspiration (Fig. 161) is similar to that produced by aspirating a knee joint or any other cavity, permitting release of fluid held under pressure. It is not wholly the calcareous deposits which cause the pain, but the accompanying inflammation and pressure within the bursa when distended. Washing out the distended bursa with normal saline, using the two-cannula method, flushes out the calcified material and relieves tension. Injection of hydrocortisone and procaine into the bursa, either alone or following aspiration, is often helpful in relief of acute symptoms. In some instances incision is necessary for satisfactory drainage, aspiration or lavage. Diathermy is effective in some cases in causing rapid absorption of the fluid

The subdeltoid bursa has a function like that of the peritoneum; it forms adhesions rapidly and also has the ability to dissolve these adhesions, followed by restoration of shoulder mobility. In the prevention of chronic difficulty resulting from acute bursitis, i.e., periarthritis with fixation, it is important that exercises and physical therapy should

be instituted to restore a normal range of motion. If muscle spasm is troublesome, it may be overcome by a short period of traction.

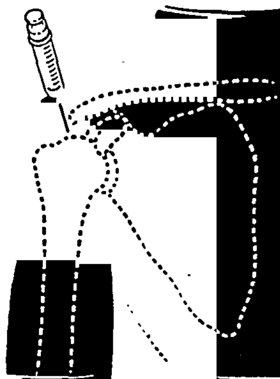


FIGURE 161. Method of aspirating swollen subdeltoid bursa of the shoulder.

Frozen Shoulder (Periarthritis; Adhesive Capsulitis)

Stiffness at the shoulder joint may be the result of either intra-articular or periarticular adhesions. The term "frozen shoulder" has been applied to this condition which may be due to adhesions forming between the joint surfaces, in the capsule or muscle, or even may follow an extravasation of blood into the tendon sheaths, particularly in the bicipital groove after trauma. In the chronic state, shoulders thus affected are stiff and the arm is held close against the chest wall. While flexion and extension at the shoulder joint are fairly free, abduction and rotation are always restricted and painful. This is a common condition found as a result of injury to the shoulder muscles, especially following a tear of the supraspinatus muscle (p. 250) or any injury to the shoulder joint (p. 260).

Despite all the attention it has received because of its economic importance, considerable disagreement and confusion still exist as to the exact cause of painful shoulder. Indeed, the exact pathologic cause is sometimes difficult to determine, since interference with any part of the "unit of motion" or scapulohumeral rhythm may cause fixation and

painful symptoms. Scapulohumeral periarthritis is now generally regarded as a stage in an inflammatory process, rather than as a disease entity. There is now more or less general agreement with Douthwaite's idea, advanced in 1938, that scapulohumeral periarthritis arises probably as a subacromial bursitis with extension of inflammation to the subdeltoid tissues, resulting in fixation, with pain, of the shoulder joint.

Clinical Picture. This condition will develop in some patients regardless of the type of treatment received during an acute bursitis, and in others who have had no treatment during the acute stage. Limitation of motion in periarthritis of the shoulder is quite characteristic. Abduction is possible to about 45 degrees; rotation, both internal and external, is possible to about 20 per cent of normal; forward and backward movement is not limited and is painless. In some cases, abduction is painful only when the arm is passing through the arc from 70 to 90 degrees, whereas abduction beyond the right angle can be accomplished without discomfort. Usually there is little change in the contour of the shoulder, but atrophy in both the deltoid and supraspinatus regions is present in chronic cases.

The typical picture clinically is that of a patient with such a disturbance in the shoulder but without other joint symptoms or a history of injury. If there is any story of trauma, it is something like "excessive work in the garden," "washing windows," or "throwing a baseball." In such instances, it is always questionable whether the alleged accident had anything to do with the condition found in the shoulder.

The clinical syndrome is not influenced in any respect by the presence or absence of calcium deposits. Roentgenographic demonstration of calcium is no indication of the severity or duration of symptoms. These deposits are found in shoulders in which there are no symptoms and have persisted in others after all symptoms have disappeared. A common finding is that calcium deposits are present in both shoulders, when only one is painful. Calcium deposits are present in approximately one-third of the cases of periarthritis of the shoulder. The condition is found equally in both sexes, and over 80 per cent of patients with this affliction are over 40 years of age. The right shoulder is involved more often than the left, but the disease often is bilateral.

Treatment. The patient's general condition, especially chronic fatigue, focal infection and glandular dysfunction, appears to be more important than trauma as an etiologic factor, although its true significance is sometimes difficult to evalute. The importance of treating the general metabolic condition has been demonstrated in patients with

hyperthyroidism with accompanying painful shoulders which showed but slight response to physical therapy, rest and general supportive therapy, but were relieved strikingly within 48 to 72 hours after thyroidectomy. Joint symptoms also improve in patients with hypothyroidism and diabetes who are treated with thyroid extract and insulin, respectively.

Since pain in these cases is definitely related to restriction of motion, the important factor in treatment is restoration of normal movements. There will be patients who fail to respond to all conservative measures, such as roentgen irradiation, aspiration (in the acute stage), hydrocortisone injections, rest, diathermy and stretching exercises, voluntary or passive. In such instances, manipulation under anesthesia is recommended, provided all acute aspects of the process have sudsided and the limitation of motion is due to old adhesions. In patients with a mild degree of fixation, gradual stretching into abduction and external rotation may be effective, but mobilization may require a prolonged period.

Manipulation under anesthesia must be done with great care, because disuse has usually resulted in considerable bone atrophy and the torsion force may produce a fracture. Major adhesions usually are over the anterior and anterolateral aspects of the joint and are broken as the arm is abducted and externally rotated; some are broken as the arm is internally rotated. Light traction should be applied following the manipulation, with the arm maintained in a position of 90-degree abduction and 90-degree external rotation. Three to 5 pounds of traction in abduction and sufficient weight to suspend the hand and maintain 90 to 115 degrees of external rotation should be used. During the first 2 days after manipulation, a complete range of motion should be attempted passively. Physical therapy, usually diathermy, is started on the third day. This is followed by active movements with an exerciser consisting of a rope on two pulleys, with hand grips (Fig. 162). Traction is reapplied after each physical therapy treatment throughout the first week. Progressive exercises with heat and gentle massage and physical therapy are continued until a full range of motion is acquired. This often requires a considerable period of time, because strength must be developed in previously atrophied muscles.

Biceps Tendinitis

In certain cases of frozen shoulder that have failed to respond to the usual physical therapy and manipulations, examination may reveal a persistent tenderness in front of the shoulder along the bicipital

groove. As Hitchcock and Bechtol (1948) emphasized, such tenderness over the bicipital groove indicates a lesion affecting the long head of the biceps muscle.

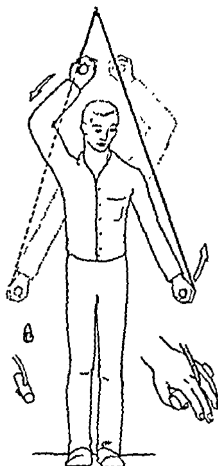


FIGURE 162. Active stretching of frozen shoulder by abduction, using rope through overhead pulley as shown.

When inflammation and adhesions are present about the biceps tendon, fixation of the long head of the tendon to the floor of the intertubercular groove greatly expedites convalescence, decreases pain and promotes rapid functional recovery. This procedure is performed through an S-shaped incision. After exposure of the tendon, abduction of the arm will demonstrate whether the humerus slides freely along the tendon or whether it is bound by adhesions under the tendon of the pectoralis major If such adhesions are present, the terminal portion of the tendon will buckle with abduction. A bed is made in the intertubercular groove by elevating a portion of the floor from the outside inward. The tendon is roughened, and is fastened beneath this osteoperiosteal flap with heavy silk sutures The transverse humeral ligament is sewed down over the tendon and osteoperiosteal flap. It

must be emphasized that the portion of the tendon lying above the transverse humeral ligament should be resected. The shoulder is then put through a full range of motion, which often loosens adhesions in the joint. The wound is closed without muscle sutures. This operation does not materially weaken the shoulder and is effective in relieving pain due to buckling and inflammation of the long head of the biceps tendon.

Traumatic Arthritis (Baseball Shoulder)

Another type of chronic disability at the shoulder is the traumatic arthritis produced along the posterior rim of the glenoid fossa. This may develop in baseball players through the constant pull on the posterior joint structures every time the ball is thrown hard. Open operation with removal of the small exostosis is recommended by Bennett (1941).

Painful Shoulder Due to Other Causes

Although the majority of cases of painful and frozen shoulder are due to the lesions just discussed, i.e., bursitis, periarthritis and tendinitis, which are viewed by some as progressive stages of the same inflammatory process, similar symptoms may result from intra-articular adhesions between the joint surfaces due to osteoarthritis or old fracture deformities. Osteoarthritis of the cervical spine and acromioclavicular arthritis may be associated with joint stiffness and pain in the shoulder. Neoplasms and referred pain from visceral organs must also be considered in differential diagnosis.

It is important to remember that in patients, particularly elderly *individuals, debilitated by some generalized disease* or recovering from abdominal or breast surgery painful shoulders are likely to develop because of muscle guarding and failure to move the arms. Whether from weakness or pain, such patients tend to sit hunched up with their arms fixed to their sides, and thus the complication of periarthritis of the shoulder develops. Shoulder complications are particularly frequent in patients who have had brain operations; in such patients, perhaps some paralysis or weakness of the arm prevents active movements. Lorenze (1956) has called attention to the frequency of shoulder complications following cardiac surgery, which are due to similar mechanisms. Shoulder complications are frequent also in patients with injuries or fractures at the wrist or elbow who keep the injured arm in a fixed position.

In all cases of this type in which shoulder and arm movements are possible, the patients should be encouraged to move the shoulder

through its entire range of motion several times each day, either actively or passively, to prevent painful shoulder complications.

FRACTURES

From the practical standpoint, the injuries of the shoulder that have to be dealt with most frequently are complex injuries, involving partial or complete lacerations of some portion of the rotator cuff encasing the head of the humerus, which may occur with or without dislocation or fracture of the humerus. However, before discussing the clinical problems encountered in these common injuries of the shoulder, fractures and dislocations of individual bones and joints of the shoulder region are briefly reviewed.

Fractures of the Upper End of the Humerus

Fractures of the upper end of the humerus without other injury are



FIGURE 163. Fracture of surgical neck of the humerus.

uncommon; they usually are associated with dislocation and ligamentous injury. Injuries of the surgical neck (Fig. 163) constitute the

largest number of such fractures, occurring most frequently in adults past middle life. They are usually produced by a fall or by a blow on the arm; they may be impacted or may present marked angulation or separation of fragments, often complicated by fracture and displacement of the greater tuberosity. The head fragment may be actually adducted and internally rotated by the pull of the subscapularis muscle if the greater tuberosity is displaced. All elderly patients complaining of pain and disability following a fall on the shoulder should be suspected of having a humeral fracture, especially when they present ecchymosis on the inner side of the arm or on the chest wall. Bony injury can usually be suspected following trauma if there is shortening of the arm with deformity and the humeral head does not move when the shaft is gently rotated. A roentgenogram, taken in two planes, if possible, usually identifies the exact position of the fracture or fracture-dislocation. A possible injury to the brachial plexus may occur with such a fracture.

Fracture of the Greater Tuberosity

This fracture is caused by direct or indirect injury, and is frequently a complication of a subcoracoid dislocation. In the severe types, the greater tuberosity with its attached muscles are displaced upward and backward. Acute local tenderness with pain increased on abduction and rotation and a history of a fall on the shoulder are suggestive of this fracture.

Treatment. In most instances, displacement is not marked and support of the arm in abduction on a light airplane splint may permit early restoration of function. In those cases with severe displacement, open operation and fixation of the displaced bony fragment becomes necessary. Retaining the arm in abduction during healing of this fracture is an essential feature as this assures an earlier return of satisfactory function.

Texts on fractures describe the treatment, but in general, every effort should be made to start shoulder motion early. In younger patients, plaster of Paris shoulder spicas with the arm in abduction may be used, but the "hanging cast" method is applicable in many patients, especially in the older ones, with circumduction exercises started early (see Fig. 157). Treatment is aimed at early functional restoration because the stiffness that follows long immobilization at the shoulder is fraught with the great danger of muscle atrophy and persistent residual scapulohumeral stiffness.

When the fracture is impacted no reduction is necessary, and the arm should be protected by a swathe and sling for only 10 to 14 days. Then active movements within the limits of pain are started. If reduction is required, protection for 4 to 6 weeks is desirable, although limited active movement can be started much earlier. In the severe fracture-dislocation removal of the head fragment is sometimes necessary, though never desirable.

Epiphyseal Separation.

Separation of the upper humeral epiphysis occurs in childhood before fusion of the epiphyses and is usually produced by a fall on the arm resulting in epiphyseal displacement. This may be mild or severe; in the latter case it is often complicated by a fracture of the adjacent diaphysis. Symptoms of pain and swelling suggest fracture, and even when roentgenograms are negative, it is well to treat the contusion as a bone injury and to immoblize it for a few weeks. A later roentgenogram may show a slight displacement.

The prognosis is good for return of normal function unless the displacement is severe. Nerve injury rarely occurs. Treatment consists of accurate reduction of severe slipping, if possible by closed reduction. In milder types, immoblization with the Velpeau bandage for a few weeks, followed by a sling and physical therapy, suffices.

Fracture of the Clavicle.

Fracture of the clavicle is usually produced by a fall on the out-



FIGURE 164. Frequent site of fracture of the clavicle with overriding.

stretched hand or by a direct blow upon the side or top of the shoulder. The usual site is at the junction of the outer and middle thirds; owing to muscle pulls, the proximal fragment is elevated while the shoulder droops forward and downward. The deformity can be seen and felt whenever there is angulation or overriding. Point tenderness is at the site of the fracture. Diagnosis is confirmed by an anteroposterior roentgenogram (Fig. 164).

Treatment. The essential feature of treatment is to reduce and immobilize the fracture, with the shoulder held backward and upward. A posterior figure-of-eight bandage is usually satisfactory, supporting the forearm and elbow in a sling (Fig. 165). Various splints in the shape of a cross, or the Sayre dressing or the Taylor brace (Fig. 166), are effective in the majority of instances. Nonunion is very rare. In most

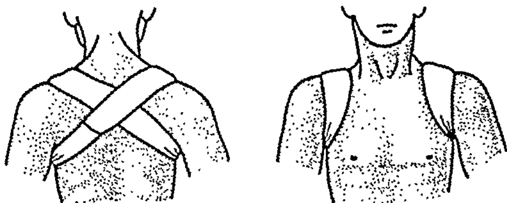


FIGURE 165. Figure-of-eight bandage. It is easy to apply but the axilla must be well padded.

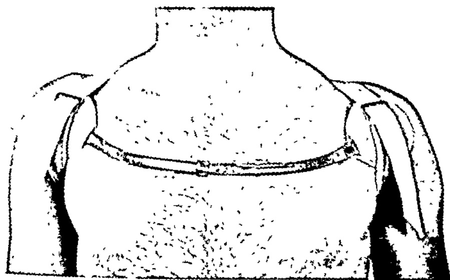


FIGURE 166. The Taylor clavicular brace. This is effective in holding the reduced fracture and is more comfortable than the usual figure-of-eight bandage.

fractured clavicles, union will be firm in 3 to 4 weeks, after which active motion can be started.

Fracture of the Scapula.

Fracture through the body of the scapula is produced by direct violence. It often is a stellate fracture. The neck or glenoid cavity may be fractured by falling on the outstretched hand or against the shoulder.

Treatment. In the body of the bone the fragments are well supported by the thick muscles on the front and back of the scapula, and immobilizing the arm to the side in a Velpeau bandage is usually all that is necessary. In the fracture through the neck and/or involving the glenoid cavity without displacement, motion should be started after 2 weeks. With displacement, recumbency and reduction by traction on the abducted arm should be instituted and continued for at least 4 weeks.

Prognosis is uniformly good in fracture of the scapular body. When fracture involves the neck or glenoid cavity, traumatic arthritis may result in a long period of disability.

DISLOCATIONS

Acromioclavicular Dislocations

That the acromioclavicular and sternoclavicular joints are not more often injured is probably attributable to the free movement at the shoulder joint proper and to the free movement of the scapula on the thoracic wall. The one force to which the clavicular joints will yield most readily is a lateral thrust, and if this is sudden and directly from the side, dislocation at the sternal end of the clavicle is most likely to occur (Fig. 167). If the thrust is from the posterior aspect of the shoulder, the acromioclavicular joint bears the strain and a partial or complete dislocation may result.

Acromioclavicular dislocations are most frequent in the adult. In the child complete or greenstick fracture of the clavicle usually results from a similar blow In any cases in which acromioclavicular injury is suspected, anteroposterior roentgenograms should be made of both shoulder regions while the patient is sitting with his arms hanging by his sides (see Fig. 10) to demonstrate the suspected dislocation at the outer end of the clavicle Whether or not there is an accompanying coracoclavicular ligamentous tear depends upon the severity of the original injury. Attempted abduction of the injured side increases the



FIGURE 167. Sternoclavicular dislocation.

obvious deformity of an acromioclavicular dislocation, the clavicle riding upward and backward in relation to the acromion in practically every case. As Sir Robert Jones (1920) remarked, "Replacement is easy but the retention of the bones in position long enough to insure strong repair is almost entirely neglected by the majority of the profession."

Early replacement and immobilization are essential in the acute case. An immobilizing splint or adhesive strapping should press downward on the outer end of the clavicle to keep the dislocation well reduced. It should be worn for 4 to 6 weeks. Another method is to reduce the dislocation manually and then insert a Kirschner wire through the acromion and acromioclavicular joint and extend it about 2 inches into the clavicle, cutting the wire off flush with the skin. The wire is withdrawn after 4 weeks.

For the chronic dislocation, operation is indicated. Bunnell (1928) described an operation which consists essentially in the recognition that the tears of the coracoclavicular ligaments must be repaired. He uses a fascial strip, reconstructing the torn conoid and trapezoid ligaments, somewhat in a figure-of-eight which extends from the corocoid and acromion processes to the clavicle. The torn capsule over the acromioclavicular joint itself is also repaired. Mumford (1941) advises excising the distal portion of the displaced clavicle. This is a simple and effective procedure.

Sternoclavicular Dislocations

Sternoclavicular dislocations are less frequent but they allow the clavicle to ride forward across the jugular notch and may be extremely disabling. Conservative treatment is usually unsuccessful because of the difficulty of holding the dislocation in a state of reduction. A conservative method recommended in only the acute case consists of applying a plaster shoulder spica in which is incorporated a screw arrangement whereby a pad exerts pressure downward and backward against the front of the sternoclavicular joint. When the spica is applied, the clavicle and the shoulder should be pulled up, out and back to restore the normal relation of the sternoclavicular joint.

Removal of the torn triangular joint cartilage and repair of the torn capsule with fascial strips may be necessary, but every effort should be made to preserve movement in this joint, for motion is essential to elevate the arm fully. Normally, in full abduction of the arm a very wide range of movement is produced in this joint.



FIGURE 168. Subcoracoid dislocation of the humerus.

Acute Shoulder Dislocations

Dislocations of the upper extremity of the humerus are more fre-

quently seen than any other dislocation of the larger joints in the body. They occur in persons of any age but particularly in young men engaged in strenuous athletics. In athletes about 50 per cent of all dislocations are at the shoulder, usually being produced by a fall or a blow on the abducted and internally rotated arm. The subacromial dislocation is the usual type, the head of the humerus being forced out of the rent in the inferior portion of the capsule and upward under the coracoid process, presenting a characteristic appearance (Fig. 168).

The shoulder is flattened and the long axis of the humerus slants toward the base of the patient's neck instead of toward the acromion process. Gentle palpation reveals the absence of the humeral head in the glenoid cavity. It may be felt under the coracoid process on rotating the shaft of the humerus. Owing to the position of the auxillary nerve about the neck of the humerus, this may frequently be damaged at the original injury; therefore, search should always be made for a weakened deltoid muscle or some disturbance of cutaneous sensation.

Treatment. If the patient is seen shortly after the injury, reduction may be attempted. This is usually accomplished without a general anesthetic, but whether under an anesthetic or not, the procedure should be smooth, slow and steady. The Kocher technic has been found satisfactory (Fig. 169), carried out as follows: With the patient seated or lying, steady downward traction is made on the flexed elbow while the opposite shoulder motion is prevented. The arm is gently rotated outward and then carried across the chest wall; reduction is accompanied by a "thud" and thereafter the arm can be moved freely. In the Velpeau position it is bandaged with the patient's hand resting against the opposite shoulder. If the dislocation has existed for some time, several days of preliminary skin traction may be useful in relaxing the muscles and slowly stretching the soft parts. As a rule a traumatic dislocation of the shoulder joint becomes irreducible after 3 weeks although there are exceptions to this rule. After reduction a cold pack may be applied to the shoulder for an hour and then a compression shrinker bandage followed by a sling. A few days after reduction heat and massage can be instituted and continued daily until normal function returns. The patient should be warned against abduction of the arm beyond 90 degrees for the first 4 to 6 weeks, and with athletic individuals a restricting harness or strapping to limit the extremes of motion may be applied.



FIGURE 169. Kocher method of reducing a simple subcoracoid dislocation in three stages: *A*. Continuous downward force exerted on the flexed elbow with one hand over the front of the elbow and the other hand holding the wrist. *B* Without lessening downward pressure, externally rotate the arm with the opposite hand and usually the head will reduce with a definite "click." *C* The hand is then brought across the chest and held by a Velpeau bandage in the position shown These maneuvers can frequently be successful without an anesthetic.

ROTATOR CUFF INJURIES OF THE SHOULDER

The large majority of injuries to the shoulder involve the musculotendinous cuff, which consists essentially of the tendons of the supraspinatus, infraspinatus, teres minor and subscapularis. These tendons fuse with the articular capsule of the shoulder joint, forming a continuous envelope encasing the head of the humerus. The first three tendons insert in their respective facets on the greater tuberosity, and the last on the lesser tuberosity of the humerus.

Although each shoulder injury is a problem unto itself, depending on the particular structures involved in the lesion, some general comments regarding them can be made by dividing them into two groups, as follows: (1) rupture of the rotator cuff following an injury without a fracture or dislocation, and (2) a rotator cuff tear following a dislocation associated with a fracture of the greater tuberosity of the humerus or following a dislocation without humeral fracture.

Rotator Cuff Ruptures without Dislocation or Fracture

Ruptures of the rotator cuff without dislocation or fracture usually occur in the fourth or fifth decade of life and usually involve degenerated tendon tissue. The supraspinatus tendon is most prone to be involved in the rupture or tear, but it must always be kept in mind that it is possible to have a severe injury to this tendon without significant impairment of total shoulder function. Whether the rupture of the supraspinatus tendon is partial or complete, it invariably occurs near the insertion of the tendon into the bony tuberosity of the humerus, since it is at this site that the degenerative changes occur.

Clinical Picture. The usual history is that of a fall or a strain or pushing on the arm with resulting pain at the shoulder, which is often referred distally to the insertion of the deltoid muscle. There is inability to elevate the arm and support it in the abducted position. In many instances, there may be inability to maintain abduction against resistance of the examiner's hand. Further information can be gained as to the exact location of the cuff tear by having the patient abduct the arm in varying degrees of humeral rotation In massive ruptures of the cuff, abduction cannot be maintained at all and the arm will drop to the side after passive support has been removed. This so-called "drop-arm sign" is fairly pathognomonic of a complete rupture of the rotator cuff. The diagnosis of partial tears is more difficult One may suspect a

partial tear from the history and physical examination. Roentgenograms are negative for fracture or calcium deposits, but degenerative changes may be seen at the greater tuberosity, such as irregularity of the cortical bone, cystic cavitation and areas of sclerosis.

Further diagnostic information may be obtained by procaine injection, after about a week, when acute swelling has subsided. If 10 cc. of 1 per cent procaine is injected into the suspected area, and then the range of the patient's abduction is definitely increased to about 150 degrees or more, the likelihood is that there is a small tear which requires conservative treatment rather than surgery. On the other hand, a complete inability to initiate or maintain abduction in any of the humeral arcs usually indicates a massive cuff tear involving all of the cuff insertion. In such cases, the value of arthrography has been demonstrated by Lindblom and Palmer (1939) and by Ellis (1953).

The technic of arthrography involves the insertion of a short-beveled needle through the clean skin 1 inch in front of the acromioclavicular joint. The needle is directed downward and backward toward the cartilage of the humeral head, and 30 per cent diodrast is injected under radiographic control. If the opaque fluid enters the joint, but flows out immediately into the subacromial bursa, it is evidence that there must be a large tear requiring operative repair.

In the series reported by Ellis, major tears were diagnosed by arthrography in 22 of 42 cases in which the procedure was used. Seven refused operation, but arthrographic findings were confirmed in 14 of the 15 patients operated upon. In the exceptional instance, the patient had probably dislocated his shoulder and had contused the supraspinatus tendon. Ellis concluded that a positive arthrogram finding, which can be obtained without delay, is an almost certain indication of a major tear requiring operation A negative arthrogram or a plain roentgenogram showing an avulsion crack in the greater tuberosity was obtained in 20 patients. Fifteen of these recovered completely; 2 others were operated on for pain and the presence of a minor lesion was confirmed Thus negative arthrography is a good contraindication to operation unless other factors require it.

Treatment. In treatment of partial ruptures of the rotator cuff, a very satisfactory result can be anticipated, in most instances, by conservative means. The small or incomplete tears may heal or the short rotator muscles of the shoulder may compensate for the loss of action of the injured tendon by a change of the rotation arc. A sling may be all that is needed during the acute painful stages. Graduated exercises

are then allowed, and most patients will regain their full range of motion in 4 to 8 weeks.

When it is obvious that the patient has a complete tear, as determined by clinical examination, procaine injection and arthrography, then surgery should be carried out promptly in order to approximate the edges of the torn tendon cuff; otherwise the patient will have a pronounced disability.

There will be some cases in which doubt may remain as to whether or not operation is indicated. If so, the tests can be repeated after 10 days to 2 weeks. By this time the reaction from injury and pain will have subsided, so that the extent of trauma can be better evaluated. If the patient still cannot abduct the arm to 90 degrees after this length of time, and if secondary changes appear, such as atrophy of the infraspinatus and supraspinatus muscles, making the scapular spine prominent, then exploration and repair are justified.

Rotator Cuff Ruptures with Dislocation and Fracture

In considering cuff tears associated with dislocations, it must be remembered that a traumatic anterior dislocation results from a disruption of either the anteroinferior supports of the shoulder joint (glenohumero ligaments and capsule) or the posterosuperior supports (external rotator tendons). The latter may consist of tendon rupture, but is more commonly an avulsion of the greater tuberosity of the humerus. Both anterior and posterior supports may be damaged simultaneously, but as a general rule, disruption of one tends to spare the other. Damage to either or both may be accompanied with potentially complicating phenomena, for example, posterior compression fracture of the humeral head, fracture of the glenoid rim, or tearing and division and displacement of the long head of the biceps.

Treatment. Dislocation of the shoulder with a fracture of the greater tuberosity or of the head of the humerus (Fig. 170) is nearly always accompanied by a torn cuff. Usually this dislocation is intracapsular. When the dislocation is reduced, the edges of the longitudinal tear generally heal well with return of good function. If the tuberosity fragment should be retracted up under the acromion, then one must presume that a large and extensive tear exists. In addition, the tuberosity fragment under the acromion acts as a wedge between the humerus and the acromion, blocking glenohumeral motion. Early operative repair should be undertaken and the tuberosity fragment restored to position and maintained by sutures and screw to allow early motion.

As has been emphasized by McLaughlin (1945), consideration of lesions resulting from disruption of the posterior stabilizers of the joint with accompanying fracture of the greater tuberosity warrants the premise that recurrent dislocations need not be feared, since the anterior



FIGURE 170. Fracture-dislocation at the shoulder joint.

structures of the joint are spared from rupture and the essential damage heals by bony union. Of 34 consecutive cases of dislocation of the shoulder with an avulsion of the tuberosity in which satisfactory reduction was achieved, none ever had a recurrent dislocation.

Complications. Surgeons have shown a tendency to focus their attention on the question of recurrent dislocation in shoulder injuries and to minimize the even more disabling complications, namely, *internal derangement of the subacromial mechanism.* This syndrome usually consists of a painful shoulder, limited motion, inconstant subdeltoid tenderness and an undue delay in return to normal function. Frozen shoulder commonly supervenes and some permanent disability is the rule. Nerve injury is present in a high proportion (30 per cent) of the cases, while this complication is present only in 4 or 5 per cent of all dislocations. Spontaneous anatomic replacement of the tuberosity frag-

ment usually accompanies reduction of the dislocation, but recovery and a normal functioning shoulder may be greatly delayed. If a complete replacement of the tuberosity fragment is not obtained at the time of reduction, the area should be explored, and the fragment either excised or fastened in place. All soft tissue damage must also be carefully repaired, as this is essential to a good end result. Operative repair must restore a smooth surface for passage under the acromion and coracoacromial ligament.

Dislocations of the Humerus Not Associated with Fracture

In dislocations not associated with fracture, the torn cuff may be the only disabling factor (see Fig. 168). When the head of the humerus is pulled out of position without any damage to the greater tuberosity, one must suspect a tear of the musculotendinous cuff. After reduction of the dislocation and immobilization of the arm, the patient can best be tested after an interval of 10 to 12 days. If he does not show any evidence of abduction after the active phase has subsided, then operative repair is indicated. Massive ruptures are likely to occur in this type of injury, and roentgenograms are helpful in suggesting such a lesion following reduction, by showing the upward riding of the humeral head. This upward riding is due to lack of support of the overlying structures, as the tear has extended through the full thickness of the musculotendinous cuff and joint capsule. Also, with the patient standing, a subluxation of the head of the humerus may be demonstrated by a roentgenogram taken with the arm hanging or holding a heavy weight. This indicates a large cuff tear which will give rise to severe disability unless it is repaired. More precise information regarding these massive tears may be obtaned by arthrography after injection of radiopaque material, as previously described.

Patients with a large tear of overlying structures of the rotator cuff are uniformly middle-aged or older, and show greatly delayed recoveries, persistent symptoms and some permanent disability. The incidence of shoulder disabilities following such lacerations is greater than that of recurrent dislocations. Such lacerations also produce more severe disturbance of function and greater pain than that experienced by the average patient subject to recurrent dislocations.

Recurrent Shoulder Dislocation

The majority of recurrent dislocations of the shoulder occur in trau-

matic dislocations not associated with fracture. Some authors have dogmatically limited themselves to consideration of one particular pathologic change as the sole cause of recurrent dislocation of the shoulder, but actually, it is impossible to state what it is that makes a particular dislocation of a shoulder become recurrent. The initial dislocation must be caused by some degree of force. This force may be severe or may seem to be slight. It would be difficult to state whether the same amount of force applied in exactly the same way and under exactly the same circumstances would constantly cause dislocation in any shoulder, or whether it is the variations in the strength or position of the investing musculature, in the strength of the anterior capsule and capsular insertions, in the depth of the glenoid, in the strength of attachment of the labrum, or some combination of two or more of these which permit one shoulder to dislocate while another will not. Certainly many shoulders withstand great external rotatory force without dislocating. Recurrent dislocations in young men usually start with a simple dislocation, and frequently result from an apparently trivial force. Why a dislocation will stay reduced in one shoulder and why it will recur in another remains unanswered. No constant pathologic change is found in shoulders operated upon for recurrent dislocation or in those examined at autopsy. Some of the changes frequently observed have been found in autopsy specimens from individuals with no history of even an initial dislocation. Some shoulders show pronounced pathologic change in one part of the joint and minimal change in another, while in other shoulders the relative amounts of change will be just reversed.

The most common changes are the humeral head defect, the detached labrum, the rounded and eburnated glenoid rim, and the increased joint space secondary to the stripping of the capsule and subscapularis from the anterior portion of the neck of the scapula. Muscular changes are difficult to evaluate, unless there is an obviously high insertion of the subscapularis or the scar of an old tear is present in the substance of the muscle (Laxity of the subscapularis must remain a clinical impression, for it is not accurately demonstrable.)

Any one of the foregoing changes may be visualized as contributing to the ease of secondary dislocations. The humeral head defect makes the size of the head considerably smaller if and when it is opposed to the glenoid rim; rounding of the glenoid rim and detachment of the labrum lessen the physical anterior buttress of the joint; stripping up of the capsule from the scapular neck weakens the attachments of the glenohumeral ligaments at the scapular attachment; poorly placed or

weakened subscapularis muscles lessen the active anterior buttress to the joint.

It seems highly unlikely that a patient can spontaneously reduce a complete dislocation of the shoulder. Conversely, if the humeral head defect is large enough and if the periosteal stripping from the neck of the scapula has been sufficient, it seems reasonable that anterior subluxation of the head of the humerus, in external rotation, can occur to the point where the humeral head defect fits the anterior rim of the glenoid cavity. Such a subluxation could easily be reduced by a shrugging motion of the shoulder. This may well account for the failure of some operations which limit external rotation of the arm to adequately correct the pathologic anatomic change involved. However, if the dislocation is complete, it usually requires manipulative reduction, probably under anesthesia.

It is striking that almost always recurrent dislocations appear in young adults in whom the external rotators are usually quite strong, and that the condition is infrequent in older adults in whom attrition of the rotator cuff is the rule. If the rotator cuff remains intact and fails to tear, an initial traumatic dislocation (external rotation) must necessarily cause the humeral head to swing medially as well as anteriorly and so drive the head more forcibly across the anterior rim of the glenoid cavity as it passes out under or deep to the subscapularis than would be the case if the cuff were to tear partially or completely.

It is interesting that recurrent dislocations, as already mentioned, occur chiefly in young men, that they are often bilateral, and that they occur sometimes in brothers. For example, Magnuson and Stack (1943) reported a patient who had bilateral recurrent dislocations, as did his twin brother, an older brother, his father and the father's brother. The frequency of occurrence in several members of the same family and of bilateralness suggests that some developmental factor may be playing a part in occurrence of shoulder dislocation, and particularly of recurrent dislocations.

As already noted, the developmental changes in man's evolution have resulted in an increased range of motion in the shoulder, but at the same time have resulted in decreased stability of the joint. Furthermore, the stability is the least in external rotation, the "position of dislocation." Dynamically, then, numerous normal activities place the shoulder in a precarious position from the standpoint of possibility of dislocation. External rotation is necessary in throwing an object, in combing the hair, in putting on a coat, in reaching for top shelves, in

"strap-hanging" in public conveyances, etc. The more rapidly and/or forcefully the arm is put into a position of external rotation, either by external force or by muscular pull, the more difficult it is to check this motion before dislocation occurs. Also, when the arm is externally rotated, it is usually in a position of reasonably wide abduction, the radius of the arc circumscribed about the shoulder joint being increased, and this, of course, adds to the functional velocity.

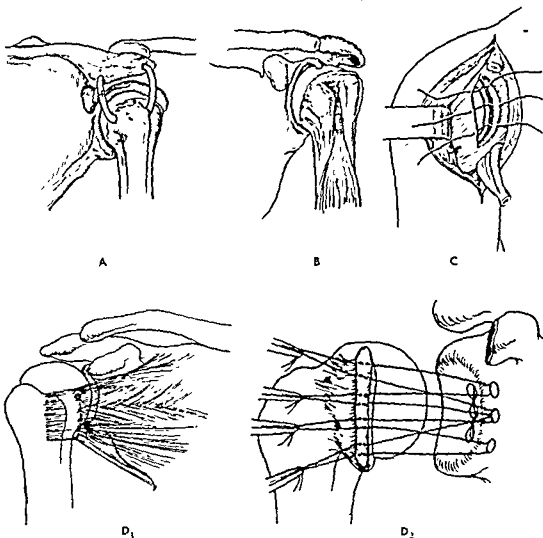


FIGURE 171. Types of operation in common use for recurrent dislocation of the shoulder: *A*, Henderson, *B*, Nicola, *C*, Bankart, and *D*, Putti-Platt. D_1, reefing the subscapularis muscle and tendon D_2, attaching redundant capsule to glenoid rim

McLaughlin and Cavallaro (1950) found that about 50 per cent of all dislocations without fracture became recurrent Redislocations occurred in 90 per cent of all patients under 20 years of age, in 60 per cent of all patients between 20 and 40, and in only 10 per cent of patients

over 40. In a series recently reported from Massachusetts General Hospital by Rowe (1956), these proportions were similar, with incidence of recurrence high in the second decade (92 per cent) and low after age 50 (12 per cent). Both McLaughlin and Cavallaro (1950) and Rowe (1956) noted that prolonged immobilization in younger patients had no influence on prevention of recurrence of dislocation. For this reason, early operative repair of the damaged anterior joint supports warrants serious consideration in all primary traumatic anterior dislocations without *fracture encountered in young male patients.*

Treatment. Historically, a multiplicity of surgical procedures (Fig. 171) has been advocated for correction of recurrent dislocations of the shoulder. The various operations are directed toward increasing the anterior support of the shoulder joint and may be classified in four main categories: (1) *bone block,* such as the Speed (1935) and Oudard (1924) operations; (2) *repair of the anterior capsule,* as exemplified by the Bankart (1938), Putti-Platt (Osmond Clarke, 1948) and Thomas (1921, 1925) procedures; (3) *suspensory operations* of intra-articular (Nicola [1929] operation and various modifications) or extra-articular types (fascial repair, as advocated by Henderson [1943] and Gallie and LeMesurier [1948], and the Hey-Groves [1933] operation); and (4) *muscle transplantations,* such as the operations devised by Bristow (Heffet, 1958), Magnuson and Stack (1943), Cotton (1910) and by Dickson *et al.* (1953). Figure 172 shows the Rowe retractor (Rowe, 1956) which is useful for shoulder joint surgery.

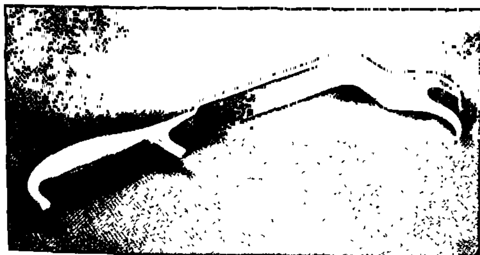


FIGURE 172. Rowe retractor, useful in shoulder joint surgery.

At present, it is the general consensus that some limitation of external rotation is essential to correct habitual dislocation of the shoul-

der; it is evident also that strenghtening the anterior support of the joint to act as a buttress when the arm goes into full abduction and external rotation is necessary. Time will prove whether still other factors are essential. If so, new technics will be designed to meet the requirements of new rationales evolving from increased knowledge of this condition.

If the surgeon is to approach the subject of shoulder injuries realistically, particularly with regard to recurrent dislocations, the operative procedure must be chosen on the basis of the pathologic condition found at the time of exploration. Because of the wide variety of pathologic findings in these cases, no one operation is going to produce satisfactory results in all cases. The important consideration in surgical treatment is to understand the functional mechanical principles involved, and the part played in the functional mechanics by each bone, muscle and tendon; then, to appraise the pathologic changes; and finally, to devise and execute an operation that will remove or correct the difficulty and restore the maximum of functioning power. If advances in surgical treatment are to continue, it is important not to become too greatly attached to any one specific technical procedure. The orthopaedic surgeon must rather be constantly seeking new ways to improve or modify his technic, being alert and watching for what each individual case can teach as to how this can best be accomplished.

Erb's Palsy (Obstetrical Paralysis)

See Chapter 15, page 673.

Sprengel's Deformity

See Chapter 3, page 227.

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5

The Arm

APPLIED ANATOMY

The shaft of the humerus is cylindrical above and prismoidal in the middle and below, presenting three surfaces and three borders. The *anterior border* begins as the anterior bicipital ridge, into which is inserted the pectoralis major muscle, and passes down the midline of the bone to terminate lateral to the coronoid fossa in a ridge separating the internal from the external surface. The *internal border* begins above as the inner bicipital ridge, into which the teres major muscle is inserted, and passes downward and backward to terminate as the internal condylar ridge. It is prominent above and below but less distinct in the middle of the shaft. The *external border* begins at the back of the greater tuberosity and passes straight down to the outer condyle, where it then becomes the external condyloid ridge. It is very sharp and prominent below, rough and well marked above, and ill defined in the middle by the passage of the radial musculospiral groove (Fig. 173)

The *posterior surface* of the shaft of the humerus is round and smooth above, becoming broad and flat below, and it is also marked by a broad shallow groove for the radial nerve. The *internal and external surfaces* of the bone can be easily identified, the internal being marked about its middle by the nutrient foramen for the nutrient artery. The external surface about the middle of the bone has a large, rough surface called the deltoid impression, which receives the insertion of the deltoid muscle, and this muscle is supplied by the axillary nerve. The radial groove crosses just below this roughened area.

Muscles. The shaft of the humerus is well covered by muscles (see

Fig. 173) for the greater part of its extent, and the outline of the deltoid muscle can be easily seen and felt. The muscles are surrounded by fascia which completely invest the limb, sending down intermuscular septa which not only serve to separate the anterior from the posterior groups of muscles, but also give a firm and unyielding origin to the various muscles of the arm and forearm.

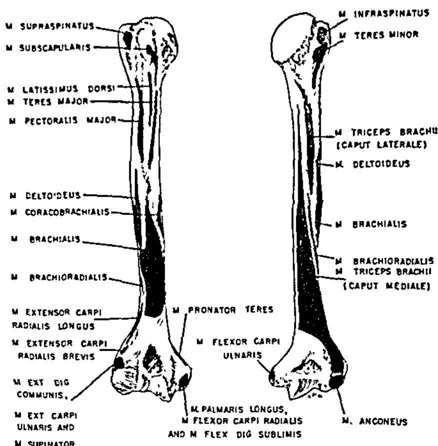


FIGURE 173. Humerus, showing muscle attachments. Red: muscle origin. Blue: muscle insertion.

The *biceps brachii* is the prominent muscle of the anterior humeral group. This muscle arises by two tendinous heads: the short head, being in close relation with the coracobrachialis at its origin, arises from the coracoid process of the scapula; the long head arises from the superior lip of the glenoid cavity, passing downward through the bicipital groove of the humerus. In the lower third of the arm just above the elbow, the biceps muscle terminates in a somewhat flattened tendon, which is inserted into the dorsal part of the tuberosity of the radius and also sends a slip, the so-called lacertus fibrosus or bicipital fascia, down into the forearm. This slip of fascia blends with the investing fascia on the inner surface of the forearm, but the bulk of

5

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medial furrow corresponding to the course of the basilic vein. This vein lies superficial to the deep fascia and superficial to the brachial vessels. The lateral furrow parallels the course of the cephalic vein. The brachial artery lies in its upper two-thirds, along the medial edge of the biceps. Obliteration of this artery at this point can be produced by pressure laterally, whereas in the lower third, as the artery reaches the anterior surface of the arm, compressions must be made backward to obliterate it.

Nerves. The *brachial plexus* is formed by the anterior cords from the four lower cervical nerves and the greater portion of the first dorsal nerve. By the time it reaches the area behind the pectoralis minor muscle it has divided into its three cords: the inner, the outer, and the posterior, the last being behind the axillary artery.

The outer and inner cords each give off a branch and these unite to form the median nerve, which lies on the front of the axillary artery at this point.

The *internal (medial) cord* alone produces the internal cutaneous, the lesser internal cutaneous, the ulnar and the inner head of the median nerves, whereas the *external (lateral) cord* forms the outer head of the median and the musculocutaneous nerves. The *posterior cord* divides into the axillary and the radial nerves, this division taking place opposite the beginning of the third portion of the axillary artery. The musculocutaneous nerve, deriving its origin from the fifth and sixth cervical nerves, supplies the brachialis and the biceps brachii muscles. The coracobrachialis muscle receives its supply from the seventh cervical nerve and the triceps and anconeus muscles from the radial nerve, which arises from the fifth, sixth, seventh and eighth cervical and first thoracic nerves. The median nerve supplies no muscle in the arm (Christian, 1915).

DISEASES

Tuberculosis

Tuberculosis of the humeral shaft (Fig. 174) is rare, but may occur at any age; in about half the cases the patients have been 20 years of age or more at the time of onset. Probably the disease, which is often of low virulence, starts in the long bone months or years before the appearance of clinical symptoms. In a series of 95 cases of tuberculosis of the long bones collected by Carrell and Childress (1940), only 11 had joint involvement.

the tendon is inserted into the posterior part of the bicipital tuberosity of the radius. This makes the biceps muscle primarily a flexor of the forearm, although with the forearm in pronation, it becomes a powerful supinator of the forearm as well as a tensor of the deep fascia of the forearm. With the elbow in extension and the humerus in external rotation, the long head of the biceps is also to some extent an abductor of the arm, but this portion primarily aids in holding the head of the humerus in the glenoid cavity. The biceps is supplied by the musculocutaneous nerve which enters the belly of the muscle in its upper third.

The *coracobrachialis* muscle, after arising from the coracoid process in common with the short head of the biceps, to which it adheres for about 2 inches, is inserted in the middle of the internal surface of the shaft of the humerus. It acts as a flexor of the arm, and together with the short head of the biceps it acts as an adductor. The muscle is supplied by the musculocutaneous nerve.

The *brachialis anticus* is a bulky, powerful muscle lying on the lower part of the front of the humerus. It arises from the distal half of the anterior surface of the humerus, extending up to the V-shaped insertion of the deltoid, as well as from the internal and external intermuscular septa. The muscle is inserted into the front of the coronoid process of the ulna. It is, therefore, a powerful flexor of the forearm on the arm, although if the forearm is stationary it may flex the arm upon the forearm as one does in chinning one's self on a bar. It is supplied by radial and musculocutaneous nerves.

The *triceps extensor cubiti* muscle arises from three heads: the long, short and intermediate portions. The internal (short) head and the external (intermediate) head arise from the whole of the posterior surface of the shaft of the humerus as well as from the internal and external intermuscular septa, whereas the long head arises from the upper inch of the axillary border of the scapula. All blend together to form the belly of the muscle which, as it passes down the posterior surface of the arm, becomes tendinous and is inserted into the olecranon process of the ulna. It acts as an extensor of the forearm upon the arm and is supplied by the radial nerve.

The *anconeus* is a small triangular muscle which is really an offshoot of the triceps extensor, and its action is to aid that muscle in extending the forearm on the arm; it is supplied by the radial nerve.

Blood Supply. In the surface anatomy of the arm can be noted a furrow along the medial and lateral aspects of the biceps muscle, the

physeal area of bone. The pathology, symptoms and treatment of osteomyelitis in general are discussed in Chapter 2.



FIGURE 175. Extensive osteomyelitis of the humeral shaft. Note long large sequestrum in middle third of shaft.

SOFT TISSUE INJURIES

Rupture of the Biceps Muscle

Rupture of the biceps brachii is not frequent, contusions to this muscle being very much more common. The long head most frequently ruptures near or at its origin at the superior rim of the glenoid cavity, within the bicipital groove or at the musculotendinous junction, and but rarely through the belly of the muscle. A slow degenerative fraying of the tendon in the bicipital groove may occasionally be seen.

Clinical Picture. When the rupture is on a degenerative basis, a final rupture may follow some trivial injury. If acute rupture occurs, it is accompanied by a sharp, stabbing pain and sometimes an audible snap, which is followed by swelling and undue prominence of the biceps muscle (Fig. 176). Whenever this occurs, the obvious swelling

Treatment. As a rule humeral shaft tuberculosis is essentially a chronic disease, but active pulmonary and other tuberculous lesions may be associated with it. Curettage, saucerization and closure have



FIGURE 174 Tuberculosis of the shaft of the humerus. (Courtesy of D. M. Bosworth, M D)

been advised; in 92 per cent of a group of patients treated in this manner the lesion healed, whereas simple incision and drainage resulted in healing in only 66 per cent of the cases. Today with the use of antibiotics better results may be expected.

Osteomyelitis

Nontuberculous infections of the bones (Fig. 175) are caused in the majority of cases by the staphylococcus and streptococcus; however, a variety of less frequently encountered organisms may occasionally be found. The shaft of the humerus is not so frequently involved as that of the tibia and femur. Osteomyelitis is usually hematogenous in origin, though it may be exogenous, and ordinarily begins in the meta-

As a rule, the older the patient, the nearer the fracture approaches the proximal end of the humerus. The common location is the middle or lower third of the shaft. Muscle pulls (Fig. 177) give rise to typical deformities depending upon the site of the fracture in the humeral shaft. When the fracture occurs below the surgical neck of the humerus and above the deltoid insertion, the proximal fragment is adducted by the pectoralis major and latissimus dorsi; a fracture just below the insertion of the deltoid produces abduction of the upper fragment through the pull of this muscle and may result in injury to the radial musculospiral nerve.

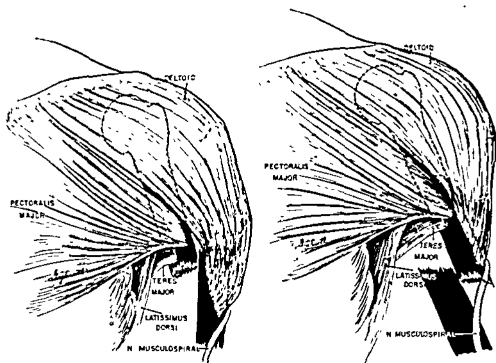


FIGURE 177. Fractures of humerus, showing muscle pulls and danger to vital structures. *Left,* fracture above insertion of deltoid muscle. *Right,* fracture below insertion of deltoid muscle.

Fractures of the humeral shaft may occur in breech deliveries. In these cases there is obvious failure to move the arm normally; abnormal mobility with accompanying deformity make a roentgenogram imperative. With these infant fractures, simply strapping the arm to the side with a little padding in the axilla to keep the arm in slight abduction is all that is necessary. The hand and fingers should be free. Remodeling of the humeral shaft is remarkable, even though angulation may be initially prominent (Fig. 178).

Clinical Picture. As in all fractures, swelling, deformity, crepitus and so forth are all characteristic features, but in humeral shaft fractures

of the bunched biceps muscle is thrown into relief if the patient supinates the forearm or flexes the elbow against resistance. The power of supination against resistance is seriously impaired.



FIGURE 176 Rupture of the long head of the right biceps muscle. Note bunching of muscle, with contraction.

Treatment. Only operative treatment should be considered. The ends should be explored, freed and sutured if it seems at all technically feasible. When the long head of the biceps is torn, it may be sutured to the short head with a very good functional result.

If the long head is torn at a lower level, it may be sutured to the lower end of the bicipital groove. If the rupture has occurred in the belly of the muscle, early repair with interrupted sutures of silk is recommended However, if the distal tendon of the biceps brachii muscle is ruptured, the tendon should be reattached to the radius (Kirschner, 1933), or even threaded through a hole drilled near the coronoid process of the ulna, to restore its function.

FRACTURES

Humeral Shaft Fractures

Fractures of the shaft of the humerus are frequently seen and occur at any point between the surgical neck and the condyles, being caused by either direct or indirect violence. A torsional or twisting force may produce an oblique or spiral fracture. Fractures may be transverse, spiral, oblique, or comminuted. A compound fracture may occur with a crushing type of injury.

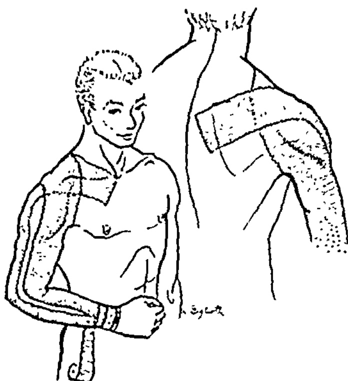


FIGURE 179. The elephant type of plaster cast. This is applied and held in place with Ace bandage. It is very useful when absolute immobilization is not necessary.

The disadvantage of the hanging cast is shown in Figure 180.

When applying the hanging cast, the patient may be seated or standing. The elbow is supported at a right angle and the forearm placed midway between pronation and supination with the thumb pointing upward (Fig. 181). A stockinet bandage is then slipped over the forearm and arm and the bony landmarks are protected with light felt padding. Sheet wadding is then firmly applied, the surgeon being careful not to have the wadding too thick and bulky. Plaster is next applied with the patient's hand in the position described and the plaster extending up on the arm. A sling loop is then placed just above the wrist (Fig. 181); the forearm hangs freely at a right angle, with a sling about the neck looped in the forearm plaster. This has an advantage in leaving the fingers and shoulder free for exercises. Circumduction exercises (see Fig. 157) should be started early whenever feasible, preferably within 48 hours, in order to prevent capsular adhesions at the shoulder joint during the fracture-healing stage.

Open operation. (1) In acute cases, heavy traction will produce dis-traction (see Fig. 180) which, if not corrected, will give rise to nonunion. In the arm area, overstretching of the musculature is easy, particularly in the transverse fracture and less so in the spiral or ob-

angulation and overriding must be recognized early and vascular and nerve damage must be carefully sought for when the patient is first seen, especially if the fracture involves the middle third of the shaft. Always check for a possible wrist drop.



FIGURE 178. Birth fracture of humeral shaft. *Left*, before, and *right*, after remodeling of bone.

Treatment. This may consist of one of the three following methods:

(1) The old method of applying a plaster spica with the arm in an abducted position and a long plaster extending down to rest on the crest of the ilium has largely been discarded.

(2) When the fractured bone is in good position and there is no nerve damage, simple temporary immobilization with the old elephant type of shoulder splint as shown in Figure 179 is excellent. In instances with impaction this type of light splint is adequate.

(3) The "hanging cast" type of plaster is very popular today and it has great advantages It allows the patient to be ambulatory and is surprisingly satisfactory in the spiral, comminuted and oblique types of fracture. It must be kept in mind that the build of the individual should be taken into account, as the heavy muscular type of patient needs a heavier hanging plaster than the slender, poorly developed individual.

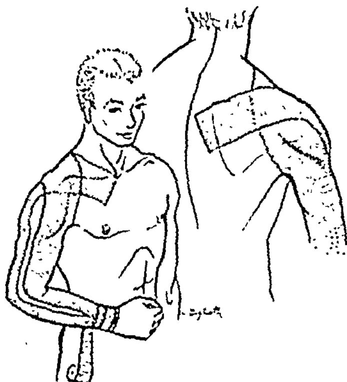


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lique type of humeral fracture. When dis-traction does occur and cannot be controlled, an open operation becomes necessary; holding the fragments close together with a long plate and packing bone chips around the fracture site is the quickest way to obtain union.



FIGURE 180 Dis-traction in a transverse midshaft fracture of the humerus The "hanging cast" with this type of fracture is likely to produce dis-traction Open reduction with fixation would be the method of choice here.

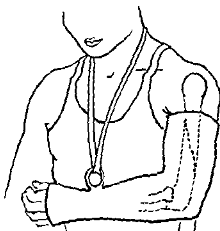


FIGURE 181. A "hanging cast" Note the right-angle position at the elbow; the forearm is in the midrotation position

(2) Another type of open operation employs the Küntscher nail. This may be satisfactory in shaft fractures of the upper and middle third of the humerus, but in the lower third the grip by the nail on the distal fragment is often not sufficient to hold the fragments, and distraction may even occur. A plate is therefore preferable.

(3) When nonunion occurs in humeral shaft fractures, it is essential to make sure that the fragments are closely approximated at operation and are then held securely immobilized. A step-cut operation (see Fig. 105) may occasionally be desirable, the fragments being fixed by screws or by plate. Sometimes removal of soft tissue between bone ends and application of a 6 to 8 hole *Vitallium plate,* with or without autogenous osteoperiosteal grafts packed throughout the fracture site, may be necessary to produce bony union. *Bone grafting,* using massive autogenous onlay or inlay grafts from the tibia or ilium, which are held in position by screw fixation, is sometimes satisfactory, though the bulkiness of the grafts does not make this method desirable.

Approach to the Humeral Shaft. Since exposure of the humeral shaft may result in radial nerve injury, both the anterior and posterior approaches to the shaft of the humerus are outlined for the reader.

The *anterior approach* to the humerus consists in making a skin incision which follows essentially the line of the cephalic vein from the tip of the coracoid process to the bend of the elbow (Henry, 1946). The vein is exposed and the outer edge of the belly of the biceps and anterior border of the deltoid muscles are identified. If exposure of the lower (distal) part of the humerus is desired the incision is deepened. This is done by dividing the deep fascia and retracting the belly of the biceps medially, thus exposing the underlying brachialis muscle; this muscle is then divided by splitting the fibers longitudinally down to the bone. Care must be taken to avoid injuring the radial nerve as it curves about the shaft of the humerus a finger's breadth below the insertion of the deltoid muscle. When the arm is adducted and the elbow flexed beyond 90 degrees, the nerve is most lax and lies in the plane between the brachialis and the brachioradialis muscles in the lower portion of the arm. A periosteal elevator can then be safely inserted to strip the brachialis muscle subperiosteally and the front of the humeral shaft can be exposed almost in its entire length. Retraction of the deltoid muscle may be safely increased if the arm is abducted.

If a *posterior approach* is desired, the humerus can easily be reached by splitting the triceps muscle longitudinally, making the in-

cision a little medial to the center of the muscle. The lateral approach to the lower end of the humerus is made by identifying the external condylar ridge and carefully subperiosteally stripping the muscles anteriorly and posteriorly. The radial nerve will be seen lying beneath the belly of the brachioradialis muscle. Whenever the posterior surface of the shaft is exposed, extreme care is necessary to avoid injury to the radial nerve.

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6

The Elbow

APPLIED ANATOMY

The elbow joint is a hinge type of joint with a range of motion of from 180 to 30 degrees (Fig. 182). The bones entering into its formation are the trochlea of the humerus, which fits into the greater sigmoid cavity of the ulna, and the rounded capitellum, which articulates with the cup-shaped cavity of the radius. These are held in close approximation by the capsule, muscles and ligaments about the joint.

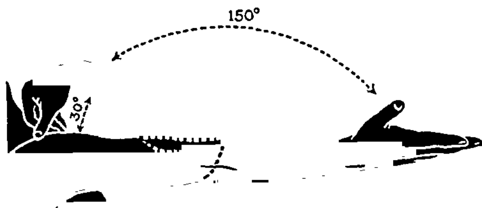


FIGURE 182. Normal range of motion of elbow, approximately 150°. Flexion to 30°, extension to 180°.

An important ligament about this joint, and yet not strictly included in the joint ligaments, is the orbicular ligament which surrounds the head and neck of the radius and holds the head in its proper relation with the elbow joint. On the front of the joint lie many important structures, among them the brachial artery and vein and their branches, the median and radial nerves and the basilic vein.

The arm and forearm when extended are not in a longitudinally

straight line but form an angle (170 degrees in males, and 160 degrees in females), because the inner condyle of the humerus is set obliquely, allowing the forearm to swing slightly away from the body to facilitate carrying objects (Fig. 183). This is the so-called "carrying angle" which, as noted, is greater in the female and is not apparent on full flexion. This angle may be disturbed by a fracture of the lower

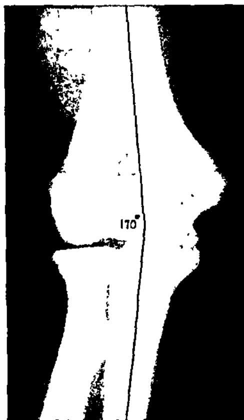


FIGURE 183. Normal carrying angle and fusion of epiphyses in a 20-year-old patient

end of the humerus or by rupture of the radial or ulnar collateral ligament. Restoration of this carrying angle following injury is important. If it is increased, the condition is called *cubitus valgus*, and if bowed medially, the condition is known as *cubitus varus*. The normal forward angle of the capitellum with the long axis of the shaft is about 60 degrees, which can be estimated by studying a lateral roentgenogram of the elbow region On the posterior surface of the joint between the internal condyle of the humerus and the tip of the olecranon is found the ulnar nerve A tingling sensation may be produced in the little and ring fingers when this nerve is pinched or struck, giving rise to this area being called the "funny bone."

The *bony landmarks* of the elbow are the internal and external condyles of the humerus and the tip of the olecranon process of the ulna. In the normally extended elbow these three bony landmarks are in a transverse straight line, whereas, with the elbow flexed these three points form a triangle.

The *bursae* about the elbow are in general four. Two of these are in relation to the triceps insertion, the smaller one being between the triceps tendon and upper surface of the olcranon; the more important of the two lies between the triceps expansion and the subcutaneous triangular area on the dorsal surface of the olecranon. This latter bursa may become swollen through repeated trauma, producing an olecranon bursitis, or "miner's elbow" (see p. 301). The other two bursae are in relation to the biceps insertion; both are small and rarely cause trouble.

Muscles. Flexion of the elbow is produced principally by the brachialis anticus and biceps muscles; extension by the triceps and anconeus muscles. The biceps, supinator brevis and brachioradialis muscles produce supination; the pronator radii teres and the pronator quadratus muscles near the wrist produce pronation of the forearm.

Blood Supply. A rich blood supply about the elbow makes the vascular circle called the *anastomotica magna,* which is formed from branches about the elbow and distributes branches everywhere except on the front of the lateral epicondyle.

Epiphyses. In the development of the elbow joint, the lower end of the humerus develops regularly through epiphyseal centers (Fig. 184) which appear in the following order: the capitellum, the internal epicondyle and the trochlea, with the external epicondyle appearing quite late, that is, between 12 and 15 years of age. The capitellum epiphysis is visible at 17 months, but the internal epicondyle is not visible before 5 years of age; the head of the radius appears somewhat later. Between 8 and 11 years of age the trochlea epiphysis and the one for the olecranon of the ulna appear, and by the fifteenth year the capitellum and trochlea have developed to such a degree that the epiphyseal line between them has become obliterated. Fusion of all the respective centers to the diaphyses of the humerus, ulna and radius has been completed usually at 16 to 18 years of age. When there is a question of injury or displacement to the epiphyses, it is always advisable to take a roentgenogram of the uninjured elbow in a similar position for comparison.

Aspiration. Aspiration of the elbow joint (Fig. 185) is best made by flexing the elbow to a right angle, and then inserting the needle

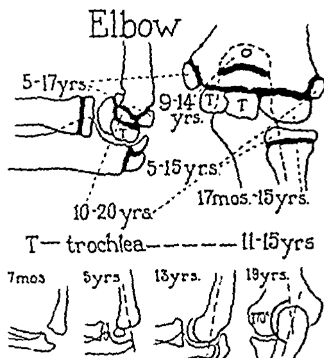


FIGURE 184 Ages at which appearance and fusion of epiphyses occur.

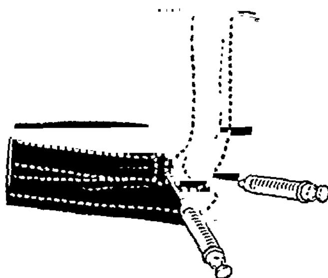


FIGURE 185. Two methods of aspirating the elbow joint.

above the tip of the olecranon parallel to the forearm, or laterally, by inserting the needle directly inward between the capitellum and the head of the radius.

DISEASES

Diseases of the elbow joint may be due to tuberculosis or to the various types of nontuberculous infections.

Tuberculosis

Tuberculosis of the elbow joint is more frequently seen than that of the shoulder or wrist, and involves more often the ulna than the humerus. This joint is the seat of tuberculosis in the adult more frequently than in the child. The pathologic picture of a tuberculous arthritis has been described in Chapter 2 (p. 46), and, as in other joints, the osteal type of tuberculosis is very much more common than the primary synovial tuberculosis. There is a dry or caries sicca type which does not present the characteristic abscess formation usually seen.

Clinical Picture. The clinical picture is that of a swollen elbow with periarticular thickening and pain which is increased by sudden movement. Because of the early muscle atrophy, the joint presents a fusiform appearance. There is a small degree of painless motion, but usually movement is greatly impaired and quite painful beyond a few degrees.

The bony landmarks of the joint are obliterated early owing to the swelling. Abscess formation often appears below and to the outer side of the external condyle of the humerus. Roentgenograms (Fig. 186A, B) show early bone atrophy with later bone destruction and "fogginess" of bone detail.

In the caries sicca type (Fig. 186C) bone destruction may be quite extensive. The bone detail is here more distinct even though destruction of the joint surfaces is evident. The clinical signs, however, are not so striking as in the usual type of elbow tuberculosis.

Prognosis. The prognosis is favorable as to life, although function, as with all types of joint tuberculosis, is always permanently impaired.

Treatment. For practical reasons one should immobilize the elbow in its optimum position for function; that is, the elbow should be kept in a position of right-angle flexion with the hand midway between pronation and supination, for this is the most useful functional position for an ankylosed elbow. If both elbows should be involved, it is preferable to put the right elbow at slightly less than a right angle and the left at slightly more than a right angle, so that the right hand can be brought to the mouth and the left can be used for cutting food, and



FIGURE 186. Types of tuberculosis. *A* and *B*, usual type with swelling and bone destruction; *C*, caries sicca type.

similar operations. Antibiotics should be used when the disease is acute.

Surgical fusion of the joint is usually advised, although in carefully selected cases an excision of the joint may be satisfactory (Kirkaldy-Willis and Braimbridge, 1948).

Osteomyelitis

Pyogenic infection often involves the elbow joint following an osteomyelitis of the adjacent metaphyses. The metaphysis is partly intra-articular with both the lower end of the humerus and the upper end of the radius, allowing rapid spread of the infection. Therefore, a pyarthrosis usually develops early. The staphylococcus or streptococcus is most commonly the invading organism.

Pathology. A primary purulent synovitis of the elbow joint alone is very rare. The condition usually spreads by extension from the bones comprising the joint, following the pathologic picture described in Chapter 2.

Clinical Picture. In acute osteomyelitis the elbow becomes swollen, tender and red with increased local heat, and unless the swelling is severe enough to obliterate the bony landmarks one can often decide which bone is primarily involved by its acute, local point tenderness. Also, the general constitutional symptoms of an acute infection are present: rise in body temperature, increase in white blood count, and frequently evidence of a general toxicity. A roentgenogram in the very early stages of an acute, purulent destructive process shows no characteristic

bone changes. The soft tissue roentgenogram may confirm the clinical evidence of increased joint fluid, but only after the first 10 days will the destructive bone changes usually be noted on the roentgenogram.

Treatment. The joint should be aspirated and a smear made to determine the type of organism. Repeated aspirations may be tried, but ordinarily incision and drainage with protective support is the method of choice in the treatment of purulent arthritis. General toxicity should be combated by the use of chemotherapy and small but frequent blood transfusions. As a rule joint function will be considerably impaired and frequently bony ankylosis will result (Fig. 187).

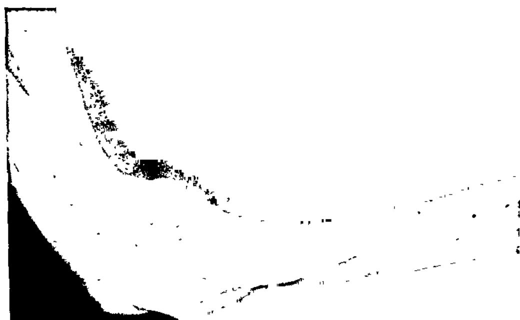


FIGURE 187. Bony ankylosis following a pyogenic osteomyelitis. This patient had both elbow joints involved. Arthroplasty later resulted in a functioning elbow joint.

The elbow should be treated while supported at the "angle of election" for arthrodesis. In unilateral infections this is a right-angle position, and when both elbows are involved and ankylosis is anticipated, one joint should be kept at 90 degrees and the other at 120 degrees.

Syphilis

Syphilis of the elbow joint is rare. Syphilitic arthritis should be suspected in those cases in which pyogenic or tuberculous organisms can be ruled out as the etiologic factor in producing acute arthritis. Congenital syphilis, a slow, chronic, infiltrating type of disease, very closely

simulates tuberculosis, and although it is more common in the knee, the elbow may occasionally be involved (Fig. 188). The symptoms are those of a chronic synovitis.



FIGURE 188. Congenital syphilis. Note bone atrophy is absent, but marked production and some bone destruction is present.

Treatment. The use of the chemotherapeutic agents, specifically penicillin, has revolutionized treatment of this disease. The use of penicillin both systemically and locally is recommended after the diagnosis is established. Support to the joint should be by temporary immobilization in plaster.

Charcot's Joint of the Elbow. Charcot's joint may occasionally be seen. Its painless, destructive osteoarthritis, its accompanying synovitis and extensive joint destruction are all characteristic features. Treatment consists in protection of the instable joint by the use of a brace.

Gonorrhea

Gonorrhea of the elbow presents clinically an acute arthritis following a known exposure to gonorrhea, although the elbow joint is not so often involved as the knee or ankle joint.

Treatment. Genitourinary treatment for the local infection, rest to the elbow by a plaster casing, and administration of penicillin (occasionally repeated aspiration of the joint) usually result in quick subsidence of the joint symptoms and partial or complete restoration of joint function.

SOFT TISSUE INJURIES

Bursitis of the Olecranon

Bursitis of the olecranon bursa, which is situated between the subcutaneous tissues and the olecranon, may arise from trauma or from local skin infection. The elbow joint is unimpaired and motion may be painless unless the extremes of motion produce tension on the bursa.

Treatment. If the bursa is acutely distended by fluid, aspiration and strapping with a felt pad over the aspirated bursa may be sufficient. In the chronic type of olecranon bursitis, the so-called "miner's elbow," excision of the sac is necessary.

Radiohumeral Bursitis (Tennis Elbow)

Although there are several other bursae about the elbow joint, the next most important clinical entity in terms of frequency is radiohumeral bursitis, epicondylitis or epicondylalgia of the elbow. It has been called a "tennis elbow" because movement, particularly during the backhand stroke, may result in a few fibers of the extensor muscles being torn from their origin in the region of the radiohumeral joint. It may also follow any occupational strain which produces flexion at the wrist and sudden extension at the elbow.

Clinical Picture. The patient complains of acute pain when the region of the radiohumeral joint near the external condyle of the humerus is palpated (Fig. 189). In severe cases a good deal of disability is present, particularly on trying to lift any object. At times the pain and persistence of symptoms may be very prolonged, resisting the usual measures of physical therapy.

Pathologically a small bursa has been found beneath the conjoined tendon over the radiohumeral joint. Though roentgenogram examination is often negative, a periosteal reaction in the region of the external condyle of the humerus, suggesting that the injury has been periosteal and muscular, may be disclosed in certain cases after a few weeks of pain.

Treatment. A cockup splint to rest the hand and a sling to support the flexed elbow will relieve the muscles from pull on the tender area. A small felt pad, with a hole in the center to accomodate the epicondyle, placed over the tender area and firmly strapped into position may give relief of symptoms. Occasionally a stretching of the elbow under anesthesia or a single injection locally of 1 per cent Novocain or

1 cc. of Hydrocortone will relieve the pain. Failing in these, an incision is made down through the fascia, well over the radial head, and the fibers of the conjoined tendons are simply split. The skin is then closed and a sling worn for a short time.



FIGURE 189. "Tennis elbow," showing area of acute tenderness.

Bicipitoradial Bursitis

After violent use of the biceps with the forearm pronated, such as in throwing a ball, there is sometimes tenderness in the region of the bicipitoradial bursa, with added local pain on resisted flexion-supination of the elbow. Treatment should be rest, heat and massage.

Strains

Muscular strains about the elbow generally result from repeated trauma of minor degree.

Diagnosis. If possible, one should isolate the lesion to one muscle or muscle group, this can be carried out by localization of the pain and point tenderness and by analysis of the type of resisted active motion which causes the greatest discomfort It is advisable to examine the elbow by roentgenograms In differential diagnosis, ligamentous sprain, bursitis and minor fractures should all be kept in mind.

Treatment. Temporary immobilization of the affected muscle in a

position of relaxation by means of removable plaster splints, adhesive plaster or a sling is the treatment of choice, with massage and heat (physical therapy) started at once, followed later by simple exercises.

Sprains

Ligamentous sprain has practically the same cause, symptoms and treatment as muscle strain, but it may be a little slower in subsiding.

FRACTURES

Fractures in and about the elbow joint (Fig. 190) are common at all ages but occur much more frequently in childhood than in adult life. They are frequently mistreated. One of the common pitfalls is

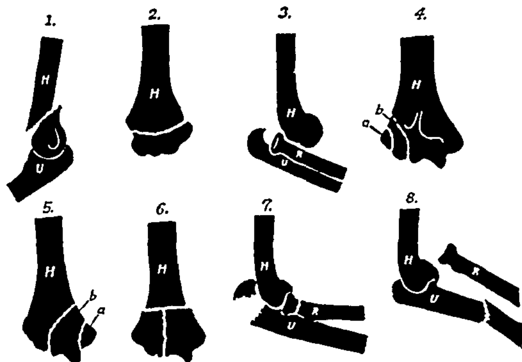


FIGURE 190. Common types of fracture about the elbow joint. (1) Supracondylar fracture; (2) epiphyseal separation, lower end of humerus; (3) posterior dislocation of both bones; (4) fracture of (*a*) internal epicondyle, and (*b*) internal condyle; (5) fracture of (*a*) external epicondyle, and (*b*) external condyle; (6) T type of fracture; (7) fracture of olecranon and head of radius; (8) Monteggia fracture (Eisendrath in Keen, *Surgery*.)

to permit the elbow to become swollen by not observing early elevation. This may delay efforts at early reduction. After a suspected fracture, proper interpretation of the roentgenogram requires a knowledge of the epiphyseal development about the elbow (see Fig. 184). Restora-

tion of the bony landmarks and carrying angle of the joint must be stressed.

Fractures in children. Reduction of fractures in children, in comparison with adults, should be obtained by the closed method, with very few exceptions. Proper function of the elbow will usually return more rapidly without open surgery. However, because of the tendency of certain fracture fragments such as the external condyle to rotate or to separate widely by muscle pull, an open operation with this type of fracture is necessary even with children. It should be done early and the fragments maintained in position without the use of metal or wire fixation if possible.

Fractures in children show a very active repair process, and time will demonstrate an amazing remodeling effect in malunions. This means that although anatomic reposition is always sought, in children one should employ open operation only as a last resort.

Fractures in adults. In the adult, open reduction is more often to be preferred because anatomic reposition is more necessary than in children. As a rule, in both adults and children the reduced elbow fracture will react unfavorably with forced early motion or manipulation. Much permanent damage will be done by forcing or stretching the elbow joint with either too active or too passive movement during the convalescent period. Occupational therapy, in which the patient can be instructed in the suitable arts and crafts, is one of the best and safest means of treating these fractures during the convalescent period. It is safer never to resort to baking and massage in the aftercare with children.

Supracondylar Fractures

Supracondylar fractures are produced by a fall on the hand or forearm, and rarely by direct injury to the back of the elbow. The great majority of these injuries occur before the age of 20.

Clinical Picture. The elbow is painful on attempted motion, and examination shows swelling, gross deformity and disturbance of the normal landmarks The distal supracondylar portion of the bone may be displaced backward or forward, with a lateral or medial shift of the distal fragment, with or without rotation. The posterior displacement of the distal fragment is most common (see Fig. 190).

Dangers and Complications. Extreme and rapid swelling of the tissues about the elbow is caused by the local injury and aggravated by the dependent attitude in which the elbow is often held. Because

of the investing envelope of fascia about the arm, elbow and forearm and the postraumatic internal hemorrhage, or occasionally from splints that are too tight, a *Volkmann's contracture* (see Chapter 7) may be produced. This is a most tragic complication. The radial pulse should, therefore, always be sought on admission, for its absence indicates that in the great majority of cases we are faced with an impending Volkmann's contracture. In rare instances a congenital anomaly of the radial artery may confuse the picture, the radial pulse being lacking at its normal site at the wrist.

Myositis ossificans (see p. 320). This is a tragic complication of elbow fractures, particularly in children, and results from forced active motion. If it develops, complete rest must be insisted upon. Excision of the bony mass is delayed at least 6 months.

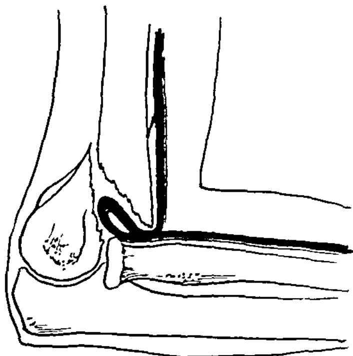


FIGURE 191. Supracondylar fracture. Proximal fragment of humerus shown impinging against brachial artery.

Another danger in supracondylar fractures is the damage that may be produced by the sharp, protruding anterior border of the proximal humeral fragment (Fig. 191). Increasing flexion of the elbow in these unreduced fractures may cause damage to the brachial vessels and nerves. Possible damage at the time of injury to the *median, radial* and *ulnar* nerves must always be ruled out.

Treatment. *Manipulation.* Early anteroposterior and lateral roentgenograms must be made and then the patient anesthetized. Traction

in the line of the long axis of the humerus is made by grasping the patient's wrist and forearm, or flexed elbow, and gently hyperextending to unlock the fragments. The thumb of the operator's other hand is placed over the front of the proximal fragment. In the usual transverse type of supracondylar fracture, the distal fragment of the hu-

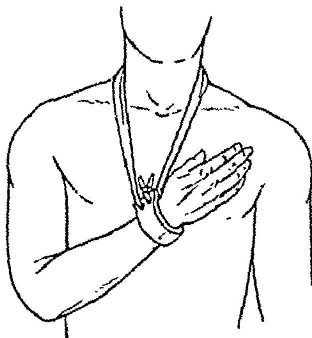


FIGURE 192 Jones' position, used for selected cases with supracondylar fracture. Always check radial pulse

merus is pulled forward, locking the fragments. The elbow is then flexed as much as the edema will safely permit. If there is lateral displacement or medial displacement of the fracture, direct side-to-side pressure can be made by grasping the elbow between the two locked hands and forcing it into position while traction on the wrist or flexed elbow is being sustained by an assistant. If the displacement is medial, reduction can be facilitated if the forearm is rotated in supination while reduction is being effected, and in pronation if the displacement is lateral. This position of the forearm is maintained when the elbow is brought into flexion and during the application of the posterior plaster splints If rotation of the humeral fragment cannot be corrected, a remanipulation or open operation in the adult patient is necessary. Early reduction is always essential in these cases, preferably under a general anesthetic. In the simple, uncomplicated supracondylar fracture, reduction is easy and a sling about the neck and wrist holds the elbow in acute flexion (Jones' position, Fig 192).

Traction with recumbency. When the swelling is so severe that manipulation would be considered an added insult predisposing to further circulatory disturbance, or when the obliquity of the fracture site renders maintenance of reduction doubtful, it is safer to put the patient

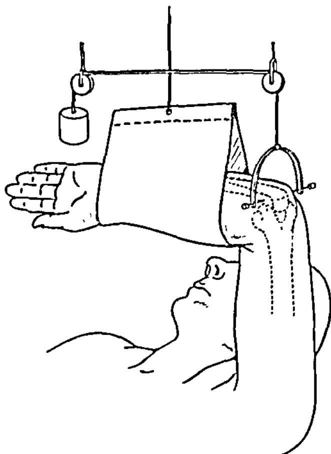


FIGURE 193. Overhead suspension with skeletal traction through olecranon

to bed and apply (1) skeletal traction through the olecranon, suspending the arm over the head (Fig. 193), or (2) skin traction, using the Dunlop method (Dunlop, 1939) (Fig. 194). After the swelling has subsided, usually within a few days, manipulation or open operation must be done if rotation of the fragments has not been corrected by skeletal traction. In children this method can be discontinued after 8 to 10 days of skeletal traction and a posterior plaster splint applied with the forearm in acute flexion. In adults a longer period of time for skeletal traction is desirable.

The patient then becomes ambulatory. It is an axiom in fracture treatment that "the quickest way to reduce the swelling is to reduce the fracture."

Splinting. The splints should not extend beyond the *metacarpopha-*

langeal joints on the back of the hand, and should be cut out low enough in front to permit full flexion of the fingers. Early finger motion must be insisted upon. To prevent subsequent cubitus valgus or varus (Figs.

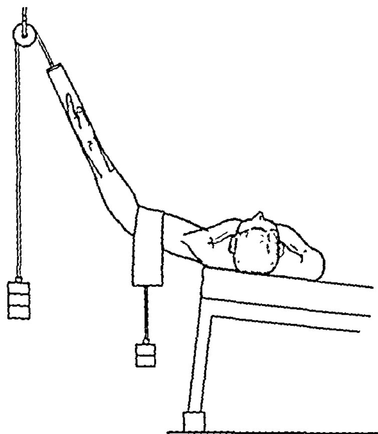


FIGURE 194 Dunlop's method of reduction.

195, 196, and 197) the arm is sometimes incorporated in a light plaster body jacket when the patient becomes ambulatory.

In the malunited supracondylar fracture which is not seen until 3 or more weeks after the injury, a better functional result is obtained in children if the malunion is left untreated until the active process of repair has subsided, and then a wedged linear osteotomy is done to correct the tilt. Whenever the deformity is not pronounced, however, the end result may be surprisingly good *in children* if no treatment other than the normal use of the extremity is advised, although accurate reduction is the desideratum.

Comminuted Elbow Fractures

T-shaped or *Y-shaped fractures* occur most frequently in adults and are produced by direct or indirect injury. In these injuries the intercondylar fractures may split into two or more fragments and the

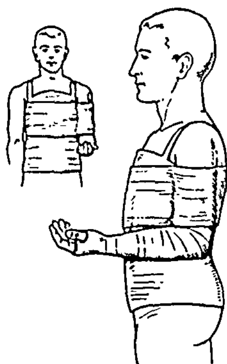


FIGURE 195. Method of immobilizing supracondylar fracture to prevent cubitus varus deformity.

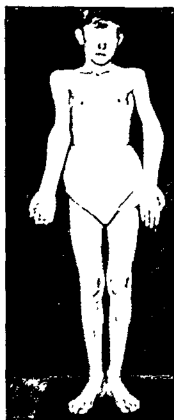


FIGURE 196. Cubitus varus deformity of left arm following inadequate splintage.

lower end of the humerus may be driven down between the condyles, rotating and displacing them, and giving rise to an obvious broadening and deformity at the elbow (Fig. 198; see also Fig. 190). It is a very difficult fracture in which to secure adequate reduction. Because the articular surfaces have been involved in the fracture, a subsequent trau-



FIGURE 197. Cubitus valgus deformity with ulnar palsy following old elbow fracture.

matic arthritis may occur, even following most accurate reduction. Nerve injuries often complicate these comminuted types of fractures. Roentgenograms are always essential before and after reduction.

Treatment. The acutely flexed position employed in the simple transverse supracondylar fracture is not applicable here. A little more than a right-angle position is often all that can be safely obtained if one wishes to retain or prevent persistent displacement of the fragments. Every effort must be made by manual lateral pressure, or the use of a wooden clamp, to mold the comminuted fragments into a satisfactory position while traction on the forearm is being applied. A snug-fitting plaster cast can then be applied if reduction is satisfactory, with the elbow in about 100 degrees extension and the forearm midway be-

tween pronation and supination. Often the patient may become ambulatory the day after reduction.

However, skeletal traction through the olecranon with the arm suspended, as in an occasional supracondylar fracture, often may be



FIGURE 198 Comminuted fracture of the elbow.

necessary (see Fig. 193). Every effort must be made to reduce widening at the elbow joint. Skeletal traction, if it produces reduction, should be maintained for 3 to 5 weeks; then the patient is allowed up wearing a sling and very guarded active exercises are begun. In these fractures perfect anatomic and functional results are rarely obtained.

Open operative fixation of the fragments with screws or pins often gives an anatomic reduction, but generally the functional result is better if the fracture can be moderately well reduced by the closed method. *Never use open reduction for this type of fracture in children.* These elbows do not need to be protected by splints or slings beyond 6 to 8 weeks, and at the end of 3 or 4 weeks limited early active motion should be begun daily. Manipulation or forced passive motion should

rarely be resorted to in any of these fractures during the convalescent stage.

Fracture of the External Condyle

When the external condyle is fractured it may include not only a portion of the shaft of the humerus, but also the epiphysis of the capitellum with the adjacent part of the trochlea, the fracture line entering into the elbow joint (see Fig. 190). Because the external lateral ligament of the elbow and the origin of the common extensor muscles are attached to this fragment, the fragment may become twisted on itself at the time of the injury, so that its fractured surface is directed outward and its articular surface inward, making open operation and correct replacement necessary. This is a serious type of fracture. If left untreated, motion is seriously impaired and the carrying angle increased. Partly because of this cubitus valgus deformity (see Fig. 197), early or late ulnar palsy may develop (Fig. 199).



FIGURE 199. Late ulnar nerve paralysis following old ununited external condyle fracture and cubitus valgus.

Treatment. If there is no rotation, closed manipulative reduction may suffice, but as a rule this type of fracture requires open reduction and fixation by the use of absorbable sutures. If some metal fixation becomes necessary, the nail or wire must be inserted proximal to the epiphyseal line in order to avoid injuring the area of subsequent growth, and must be removed after a few weeks.

Displacement of the External Epicondylar Epiphysis

Displacement of the external epicondylar epiphysis may be seen occasionally. This epiphysis develops as a separate center of ossification; it appears at about 12 years and fuses at 14 or 15 years of age. As this epiphysis is inconstant and remains as a separate center only for these few years, avulsion of the external epicondylar epiphysis is rare.

Fracture of the Internal Condyle

Fractures of the humerus may include fracture of the entire internal condyle (see Fig. 190). The fracture line is usually vertical, involving the articular surface in the region of the trochlea.

Treatment. This is not a common type of fracture, and unless there is gross displacement it can be easily reduced and a plaster splint applied with the forearm in acute flexion and pronation. If there is gross displacement, Kirschner wire traction through the olecranon process may suffice; if not, open operation and visual reduction are necessary, with fixation of the fragment to the humerus. The forearm should then be immobilized at right-angle flexion and pronation. Fractures about the internal condylar region require immobilization for about 4 weeks, followed by active exercises.

Fracture of the Internal Epicondyle

A more common type of fracture involving the internal aspect of the elbow is fracture or displacement of the internal epicondyle of the humerus (see Fig. 190). It is often simply an epiphyseal separation in which the epicondyle is pulled downward and forward. In some instances the detached fragments may be displaced between the humerus and the ulna with the ulnar nerve caught between. A separate center of ossification for the internal epicondyle is visible by roentgenogram between 5 and 17 years of age, and therefore a comparison with the opposite elbow in the same position will disclose whether the epicondyle has only slightly changed its position or whether it is grossly displaced and rotated.

Treatment. Closed reduction may suffice in the simpler type of displacement. If there is separation and gross displacement with or without rotation, an open operation and replacement of the epicondyle is the method of choice. It may be fixed by catgut sutures into its normal position, or a Kirschner wire may be used to immobilize it temporarily with the forearm in pronation and flexion. Immobilization of the arm

for a few weeks in a plaster splint is all that is necessary before withdrawing the wire and beginning active motion.

Fracture of the Olecranon Process

This may occur through direct or indirect violence and is usually a transverse or slightly oblique type of fracture at various levels on the olecranon process of the ulna (see Fig. 190). The power of the triceps may often produce wide separation of the fragments. On examination there will be a history of injury, localized tenderness over the olecranon and considerable local swelling, and if the fracture is complete, an inability to extend the flexed forearm. If the fragments are separated widely, this fact can often be detected by palpation. Roentgenograms confirm the diagnosis.

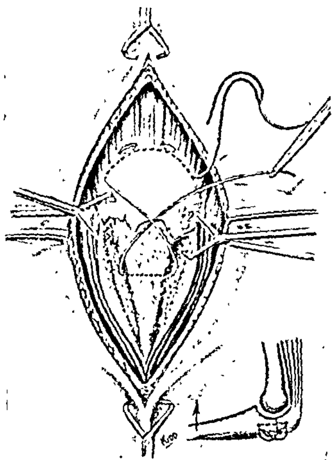


FIGURE 200 Operation for reduction and suture of fracture of olecranon. By crossing the stitch over the back the fragments are pressed firmly together when the elbow is flexed. A simple square stitch (*inset*) may also be introduced. (From Watson-Jones, R. *Fractures and Joint Injuries*, Vol. I, 4th ed, Baltimore, Williams & Wilkins, 1952. Courtesy of E. & S. Livingstone, Limited)

Treatment. Occasionally in those cases without separation, simple extension of the forearm on a splint suffices; however, as a rule separation has occurred through muscle pull, and open operation with internal fixation of the fragments is indicated. The simplest method is by drill holes through the fragments (Fig. 200). Not only should the fragments be approximated, but the wound should be inspected for a tearing of the lateral expansions of the capsule; these, if torn, must be repaired. Absorbable suture repair is preferable to metal fixation, although at times in the adult a Küntscher rod or Steinmann pin may be inserted through the olecranon and down into the long axis of the ulna. In the case presenting small fracture fragments, excision of the fragments may be done with repair of the tendon, using strips of fascia lata cut from the thigh to effect the repair. The extremity is then immobilized by anterior and posterior molded splints for 3 weeks, followed by guarded active exercises and very gentle massage.

Fracture of the Coronoid Process

This fracture is rather unusual but may be produced by the action of the brachialis anticus muscle through indirect violence, or as a complication of a posterior dislocation of the elbow. Clinically the fracture is difficult to recognize and the diagnosis is rarely made except by careful study of the roentgenogram (Fig. 201).



FIGURE 201. Fracture of coronoid process of ulna.

Treatment. Usually these fractures unite satisfactorily if the elbow is placed in acute flexion for a few weeks, but if the fragment is displaced into the elbow joint or the fracture fails to unite, excision of the loose fragment may be necessary.

Fracture of the Head or Neck of the Radius

This type of fracture occurs fairly frequently and may result from direct or indirect violence. The simplest type is the longitudinal, incomplete fracture through the head of the radius without displacement. There are varying degree from the common transverse (see Fig. 190) type up to the comminuted fracture through the neck with complete displacement of the fragments. In children an epiphyseal separation with rupture through the orbicular ligament occurs fairly frequently.

The diagnosis depends upon the history of injury, localized tenderness, deformity over the head of the radius and limitation of rotation. Roentgenograms will confirm the diagnosis.

Treatment. If there is no displacement and the fracture is of the simple linear type, immobilization for a few weeks with the forearm in full supination and the elbow flexed is all that is necessary.

With displacement, the condition is far more serious and the treatment will depend to a great extent upon the age of the patient. As a rule, with displacement, open operation will be necessary, but in children reposition and repair of the orbicular ligament is far preferable to excision. In the older individual after the age of fusion, which is about 17 years, excision of the head of the radius may be accomplished safely. If excision is decided upon, it must be done shortly after the accident, and not delayed for several months, if the best functional result is to be expected.

Complications. In children excision of the head of the radius may give rise to an increase in the carrying angle and the development of a change in relationship between the tips of the styloid and ulnar processes, resulting in radial deviation of the hand (Lewis and Thibodeau, 1937). As a further complication of radial head removal in children, late ulnar nerve pressure symptoms have been reported. Whenever the head is removed, it should be entirely removed, and the neck smoothed off and covered over with adjacent soft tissues. Recovery of function is slow following excision of the head of the radius, and complete extension and rotation may be permanently restricted.

DISLOCATION

Dislocation of the elbow may be *anterior, posterior, lateral* or *medial* and may be complicated by a fracture of any of the bones entering into the formation of the elbow joint. Posterior dislocation of the elbow is an injury that may occur at any age and is the most common type; it is often complicated by a fracture of the coronoid process.

Forward dislocation is usually accompanied by fracture of the olecranon and forward dislocation of the head of the radius. The posterior dislocation is usually caused by a fall on the outstretched hand with the forearm supinated and the elbow extended.

Treatment. A roentgenogram is essential and reduction should be effected early. Prompt open reduction of the ulnar fracture and dislocation of the head of the radius is important if satisfactory function is to be expected.

In the *simple posterior dislocation of the ulna without fracture,* traction can be made upon the hand and forearm while the knee of the operator is placed in the anterior surface of the semiflexed elbow (Fig. 202); a combination of these forces usually allows reduction to be accomplished gently and easily. There is a distinct "click" as the dis-

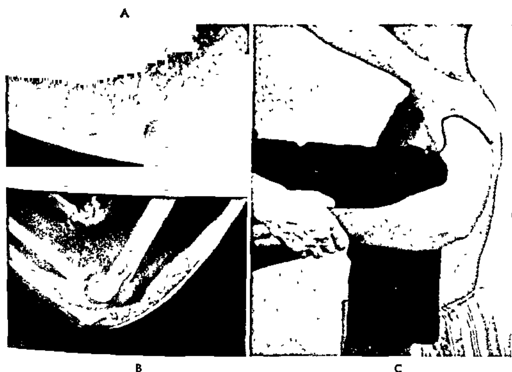


FIGURE 202 Simple posterior dislocation without fracture. *A* and *B*, before and after reduction; *C*, method of reducing simple posterior dislocation of elbow uncomplicated by fracture.

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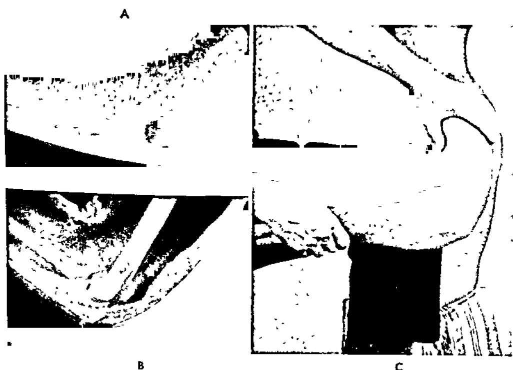


FIGURE 202. Simple posterior dislocation without fracture. *A* and *B*, before and after reduction; *C*, method of reducing simple posterior dislocation of elbow uncomplicated by fracture.

location is reduced; free flexion of the elbow is then possible. The elbow is then flexed in as much of a right-angle attitude as the swelling will permit, always checking the radial pulse. A posterior molded plaster splint is applied. Immobilization is continued for several weeks; elevation of the elbow may be necessary to combat the swelling. In those cases of fracture-dislocation, the fractured coronoid process is sometimes simultaneously reduced at the time of the dislocation reduction.

All dislocations must be reduced as early as possible, and if there are unreduced fracture elements, they can be replaced by open operation about a week later or as soon as the swelling has sufficiently subsided.

In the *car-swipe* type of elbow fracture accompanied by severe comminution of the fragments, with or without dislocation of the elbow, decision as to open or closed operation must depend upon the individual combination of fractures. As a rule every effort is made to reduce the fragments by closed manipulation before resorting to open surgery.

Old Unreduced Fracture-Dislocation

The old unreduced fracture-dislocation of the elbow (Fig. 203)

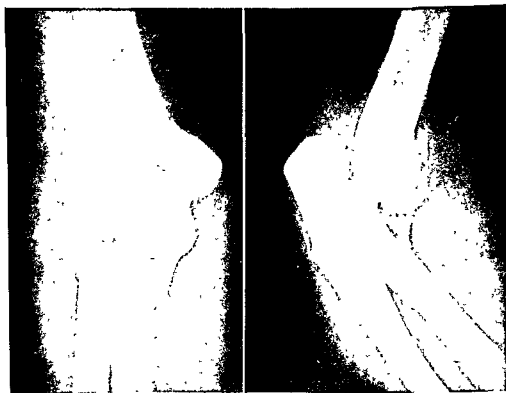


FIGURE 203. Posterior fracture-dislocation of both bones of the forearm.

results in severe limitation in motion and gross deformity. It rarely lends itself to any satisfactory reduction if manipulative reduction has been postponed beyond several weeks from the time of injury. One must, *in the adult only,* consider an open reduction, excision of the joint or an arthroplasty. Arthroplasty should not be undertaken earlier than 6 months after the accident.

Dislocation of the Head of the Radius

Dislocation of the head of the radius is seen only occasionally as a congenital deformity, but traumatic dislocation or subluxation of the head of the radius is most common in early childhood and may be produced by the mother suddenly jerking upon the child's arm or by a relatively minor fall with the elbow extended. In the *simple acquired subluxation,* persistent pronation and restricted flexion are present without gross disturbance in the anatomic landmarks. At times a roentgenogram of the opposite elbow may also disclose a slight displacement.

In the *frank traumatic dislocation* of the head of the radius, there is a limitation of motion and a gross elbow deformity with an increase in the local disability (Fig. 204). Dislocations are usually anterior and may be accompanied by a fracture of the olecranon. If the upper



FIGURE 204. Traumatic anterior dislocation of head of radius in a child.

third of the shaft of the ulna is fractured and the radial head dislocated, it is called Monteggia's fracture (see Chapter 7).

Treatment. The treatment in simple subluxation is forced supination of the forearm and is accompanied, on reduction, by an audible snap. In the complete dislocation without fracture, traction can be made in the long axis of the arm and, while slowly extending and supinating the elbow, pressure is exerted over the front of the head of the radius. If, however, reduction is not done early, the torn orbicular ligament, through which the head of the radius has buttonholed, may be sufficiently bound down about the neck to render closed reduction impossible. In these cases reduction can best be effected by an open reduction with repair of the orbicular ligament.

If the case is complicated by a fracture of the upper third of the shaft of the ulna (Monteggia's fracture), this must be reduced by open operation. They are difficult fractures. Open reduction of the radial head, at the same time plating the ulna or inserting an intramedullary nail into ulna, is the method of choice. (See Monteggia's fracture, page 328.)

Summary of Elbow Injuries

The prognosis for return of normal function in the simple dislocation is excellent if early reduction has been gently effected. In those cases complicated by severe fracture or in which reduction has been delayed until considerable force is necessary to accomplish it, the prognosis is poor. In the treatment of all fractures and injuries about the elbow the development of myositis ossificans is a potential danger. This is particularly true in children when subjected to early forced motion following fracture or dislocation.

Myositis Ossificans

Although traumatic subperiosteal ossification about the joints may complicate other fractures, it is an outstanding complication of elbow fractures in children that have been subjected to delay in reduction or to forced passive motion or deep massage. In children dislocation of the elbow is more frequent than that of any other joint; the periosteum is severely damaged and ossification more frequent than in fractures. When the periosteum is stripped up ossification follows manipulative movements, developing either in the fibers of the brachialis anticus or in the adjacent tissue.

Treatment. This bony mass is seen in the roentgenogram (Fig. 205)

after its formation and increases in size for a matter of months. It then may slowly regress if the aggravating factors are discontinued, although the older the patient the less the resorptive powers.



FIGURE 205. Myositis ossificans. This condition developed following strenuous activity plus physical therapy after excision of fractured radial head.

The prime essential is to stop the treatment that produces traumatic subperiosteal ossification; this is usually the passive "pump handle" manipulations that so many of these patients receive. Massage to the elbow structures, the carrying of heavy weights in the hand, the effort to force extension and flexion must be discontinued. The patient may be permitted to move the elbow actively within the limits of pain. A "hands off, waiting policy" may salvage motion, but any early surgical removal of the myositis ossificans mass is always contraindicated.

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7

The Forearm

APPLIED ANATOMY

The forearm includes that area of the upper extremity extending from the elbow to the wrist joint. The radius and the ulnar bones are joined by a strong interosseous membrane; these fibers point downward and inward between the inner border of the radius and outer border of the ulna, the membrane being pierced in the lower third of the forearm by the foramen for the anterior interosseous artery. The whole membrane occupies about two-thirds of the length of the shaft of these bones, and not only increases the area for the origin of the muscles of the forearm but also enables the ulna to receive a portion of the shock when one falls on one's hand. The radial shaft is bowed with the convexity slightly outward and backward, and both bones present three surfaces and three borders. The posterior border of the ulna is prominent and well marked subcutaneously throughout, terminating on the back of the wrist as the styloid process.

Muscles. On the lateral border of the forearm is the brachioradialis muscle and the radial extensors of the wrist. These muscles to the wrist and fingers are crossed by the extensors of the thumb about 1½ inch above the styloid process of the radius. Along the medial portion of the upper forearm is the pronator radii teres muscle, which runs obliquely downward and laterally to insert into the radius about its middle third. The muscles on the forearm are usually divided into the volar and dorsal groups. Those on the dorsal surface are again subdivided by intermuscular septa into superficial, radial and deep groups, whereas those on the front contain five superficial and three deep muscles. The

superficial group all arise from the inner condyle of the humerus, the investing fascia and the intermuscular septa (Fig. 206).

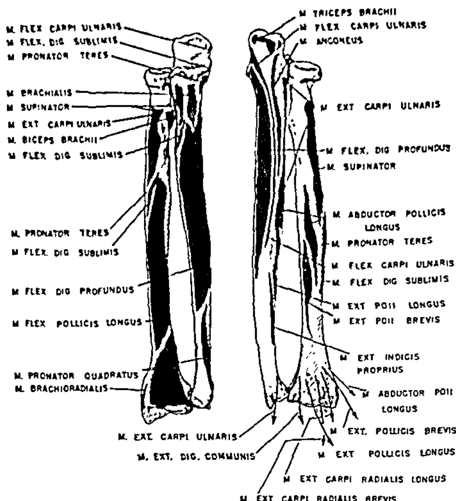


FIGURE 206. Radius and ulna, showing muscle attachments. Red: muscle origin. Blue: muscle insertion.

Every muscle found on the front of the forearm produces flexion or pronation; those on the posterior surface produce extension or supination (Fig. 207).

Covering the muscles of the forearm is a strong fibrous membrane called the deep or investing fascia, which is continuous with the investing fascia of the arm. This forms a complete investment, and from it septa arise which not only divide the different layers of muscles one from another, but also serve to give strong and firm attachment to the muscles. Thus, the forearm is divided into separate fascial compartments which become thicker at the wrist joint and give support to the extrinsic muscles of the hand. These thickened portions of the fascia at

the wrist are designated as the anterior and posterior annular ligament.

Blood Supply. The arteries of the forearm are the radial and ulnar and their branches. The radial artery begins about ½ inch below the bend of the elbow, where the brachial divides, and passes downward

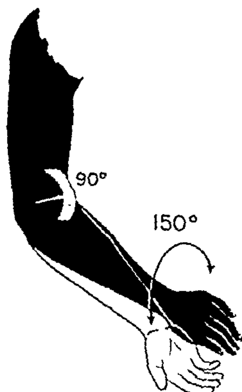


FIGURE 207. Total range of normal rotation of forearm, approximately 150°. Elbow should be held at a right angle while forearm is pronated and supinated.

and outward toward the wrist, where it lies in the anatomic "snuffbox" and becomes the radial artery of the wrist. In fractures of the scaphoid bone, there is usually pain on pressure in the "snuffbox" area. The belly of the brachioradialis muscle lies to the outer side of the radial artery, the pronator radii teres muscle lying medially to it at the beginning, and the flexor carpi radialis muscle lying on its inner aspect later. The artery is accompanied by satellite veins on either side. In the middle third of its course, the artery has the radial (musculospiral) nerve to its outer side.

The *ulnar artery* is larger than the radial, and is the other terminal branch of the brachial artery, passing down and inward in the upper third to descend along the inner side of the front of the forearm and wrist where it terminates, becoming the ulnar artery of the hand. In the

first part of its course it lies beneath all the muscles of the superficial group except the flexor carpi ulnaris, descending in the forearm with the tendon of the flexor carpi ulnaris muscle on its inner and the flexor sublimis digitorum muscle on its outer side. It is accompanied by its satellite veins, and in its lower two-thirds has on its medial side the ulnar nerve, and in the upper portion of the forearm the median nerve.

Nerves. The *ulnar nerve,* the last branch of the internal cord of the brachial plexus, contains fibers from the eighth cervical and first thoracic nerves. It runs downward in the groove between the medial epicondyle and the olecranon, continuing its course on the medial side of the ulnar artery to just above the ulnar styloid process where it enters the palm of the hand and divides into a superficial and deep branch. In the forearm, it supplies muscular branches to the flexor carpi ulnaris and the inner half of the flexor profundus digitorum muscles, as well as dorsal and palmar cutaneous branches.

The *median nerve* lies in a line drawn from the medial side of the brachial artery in the antecubital fossa of the elbow to a point just medial to the tendon of the palmaris longus muscle at the wrist. It is the joint product of the internal and external cords of the brachial plexus, being derived from all the anterior cords entering into the plexus. It gives off branches to all the muscles of the superficial group on the front of the forearm with the exception of the flexor carpi ulnaris, whereas the deep group are supplied by the anterior interosseus, a branch of the median.

The *radial (musculospiral) nerve* is the largest branch of the brachial plexus, supplying all the muscles on the back of the arm and forearm. It contains fibers from the sixth, seventh and eighth cervical nerves and often from the fifth cervical or first thoracic nerves. The medial and lateral antibrachial cutaneous nerves supply the skin on the front of the forearm; the thoracic, medial and lateral antibrachial cutaneous nerves supply the skin on the dorsum of the forearm.

DISEASES

Tuberculosis

Tuberculous disease of the radius or ulna rarely occurs (see Tuberculosis of the Long Bones, Chapter 2, p. 53).

Osteomyelitis

The nontuberculous type of osteomyelitis of the forearm (Fig. 208)

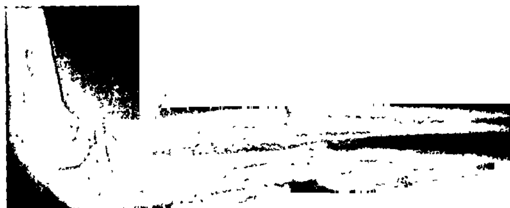


FIGURE 208. Osteomyelitis of the ulna. This followed a compound fracture of the ulna combined with a simple fracture of the radius. Note that bony union in the radius is almost complete, whereas the ulna shows nonunion and sequestrum formation. There is marked periosteal proliferation which extends up to but not across the line of fracture of the radius accompanied by marked bone decalcification in the ulna.

is fairly common; the pathologic and clinical picture of osteomyelitis and its treatment are discussed in Chapter 2.

SOFT TISSUE INJURIES

The forearm may suffer contusions, lacerations and sprains, which may be accompanied by fracture of one or both bones of the forearm, with or without serious injury to the muscles, nerves and blood vessels.

Tenosynovitis

The tendon sheaths of the forearm muscles, especially the flexors, may become inflammed as the result of injury or disease.

Acute Tenosynovitis. The symptoms of an acute tenosynovitis are discomfort and frequently pain on motion of the affected tendon. There is slight local swelling as well as a "silky crepitation" on palpation and a sensitiveness to pressure. The tendons in the forearm and about the ankle are particularly prone to develop a tenosynovitis.

Treatment consists of rest and compression such as a light splint and an Ace bandage. A crisscross adhesive strapping supplying rest and compression to the involved tendons is usually effective. Meticortelone, 1 to 2 cc. injected locally into the involved tendon sheaths, shortens the convalescence.

Chronic Tenosynovitis. Chronic tenosynovitis with progressive enlargement of the tendon sheaths suggests tuberculous disease of the

sheaths. The swelling may even extend into the palm of the hand and may be of long duration. The sac is often filled with so-called "rice bodies," small millet-sized cartilaginous masses. Treatment for this consists of radical removal of the loose bodies and excision of the affected tendon sheaths.

FRACTURES

Ulnar Shaft Fractures

These fractures are usually due to direct violence, such as a blow on the forearm or a fall upon the pronated forearm. When the force in falling on the outstretched hand is transmitted through the radius, it almost never results in a fracture of the ulna only. The ulna is subcutaneous throughout its length and a direct blow may result in the injury being a simple or compound fracture. The shaft is most frequently broken obliquely or transversely; these fractures usually occur in the lower half where the bone is rather slender (Fig. 209).

In children the fracture may be greenstick in type. There may be a combination fracture of the shaft of the ulna with dislocation of



FIGURE 209. *Top*, fracture of the lower portion of ulna only. *Bottom*, Monteggia type of fraction-dislocation

the head of the radius (Monteggia's fracture-dislocation); therefore, roentgenograms should include the whole forearm. If the shaft fracture involves only the ulna and presents overriding or angulation, it may cause a dislocation of one of the radioulnar joints either at the elbow or wrist.

When the head of the radius is dislocated forward and the ulnar fracture angulated in the same direction, it has been called a Monteggia type of fracture (Fig. 209). The reverse of this deformity is sometimes seen, i.e., the radial head is dislocated backward and the upper fourth of the ulna fractured.

Clinical Picture. Because the posterior border of the shaft of the ulna is subcutaneous, diagnosis of fracture can easily be made and crepitus demonstrated. Swelling, local tenderness and bony deformity are present.

Treatment. In those cases without displacement, simple immobilization in a strong, posterior molded splint from the middle of the arm to the base of the fingers is all that is necessary; in those cases with displacement, manipulation and reduction should be done under either general or local anesthesia. Care must be taken to use a moulding force when applying the plaster in order to restore the width of the interosseous space and avoid the chance of cross union between radius and ulna. The forearm is immobilized with plaster extending from the middle of the arm to the fingers, with the forearm in pronation and about a 90-degree angle at the elbow. Rarely is an open operation necessary to correct the displacement when only the ulna is fractured, but it is necessary with the Monteggia fracture.

Both *anteroposterior and lateral roentgenographic views* are essential. The prognosis for union and good function is excellent with simple ulnar fracture. Nonunion of the shaft of the ulna when it alone is fractured is very rare, but this bone does unite rather slowly.

Monteggia's Fracture-Dislocation

This is a fracture of the upper quarter of the ulnar shaft accompanied by a dislocation of the radial head (Fig. 209). If seen within the first few days after injury, reduction of the radial head and correction of the angulation of the ulna can often be obtained by manipulation. If there is overriding of the ulna, an open operation and fixation of the fracture by a plate or Küntscher nail is necessary as well as open reduction of the radial head. Union may be expected to be slow.

In the old, unreduced Monteggia's fracture in which ulnar malunion

has occurred, excision of the radial head may have to be done; whereas if there is a complicating ulnar nonunion, both radial head excision and bone grafting on the ulna are necessary. Bone union will be slow.

Radial Shaft Fracture

Fracture of the shaft of the radius may occur by direct violence or by a fall upon the outstretched hand. The commonest site of fracture is the middle of the lower third of the shaft proximal to the site of a Colles' fracture (see Chapter 8, p. 346). The fracture line is usually slightly oblique or transverse; in children the greenstick or incomplete type of fracture is frequently seen. If the fracture occurs *above* the insertion of the pronator radii teres muscle, the distal fragment is pronated by the action of this muscle; when it occurs *below* the muscle insertion, the proximal fragment is rotated into pronation. In the first instance, the forearm must be supinated to bring the distal fragments in line with the proximal; whereas in the latter case, the forearm must be pronated in order to accomplish the same accurate reduction. The flexor and supinator action of the biceps muscle with rotation in the longitudinal axis, displacement of the fragments and the medial and rotary pull of the pronator radii teres are forces that must be reckoned with in the reduction of all radial shaft fractures. If there is much overriding, it will be accompanied by malalignment at the lower end of the radius, and sometimes the inferior radioulnar joint is disrupted and widened, whereas the radial length is shortened (Fig. 210).



FIGURE 210. Fracture of radial shaft.

Clinical Picture. When the shaft of the radius is fractured, the head of the radius does not move when the lower fragment is rotated. A false point of motion can usually be palpated and angulation noted along with the local swelling. The inferior radioulnar joint also should always be examined.

Treatment. After the fracture is reduced by manipulation or by open operation, plaster is applied from the middle of the arm to the metacarpophalangeal joints of the fingers, with the elbow at a right angle and the forearm in pronation or supination as indicated above. If the fragments are displaced, continuous longitudinal traction with the elbow flexed may permit reduction, but if there is an oblique line of fracture an open operation, plating or screwing the fragments together, will usually assure a better result. Immobilization should be continued until clinical and roentgenographic evidence show bony union. This is usually between 4 and 6 weeks. As a rule the prognosis is excellent for return of full function. Figure 211 shows one method of rehabilitating a badly deformed forearm with nonunion of radius.

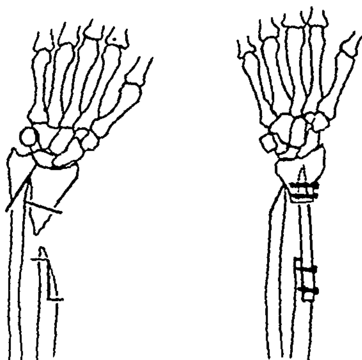


FIGURE 211 Operative method employed for nonunion of radius, using a fibular graft plus excision of the lower ulna. (See also Fig. 106.)

Fracture of the Shaft of Both Bones of the Forearm

Fracture of the shaft of both bones of the forearm may occur by both direct and indirect violence and is particularly common in children. It can be a very difficult fracture to treat, and most often occurs in the lower half of the forearm, whether the bones are broken at different levels or at the same level (Fig. 212).

Clinical Picture. Usually, a history is given of a fall upon the outstretched hand, followed by immediate pain and complete local dis-

ability. Deformity and crepitus are prominent, as well as considerable local swelling.

Treatment. One should attempt careful closed reduction with longitudinal traction, the elbow being flexed at a right angle, and if the fracture is transverse, the radial fragments can usually be locked into position.



FIGURE 212. Fracture of both bones of forearm.

When the case presents severe swelling, suspension of the part to reduce the swelling may have to be the first consideration. In these cases a Kirschner wire is inserted transversely through the radius and ulna just above the wrist joint and another through the supracondylar region of the humerus. Traction then often permits reduction of both fractures. If this method proves unsuccessful, open operation can be done after the swelling has sufficiently subsided.

Particular attention must be paid to obtaining anatomic reduction at the site of the fractured radius; this is not so essential in the ulna. Attention should be paid also to both angulation and rotation. The dangers of cross union between the fractured ulna and radius, if the fracture occurs at approximately the same level in the bones, is very real and is important to avoid. In both closed and open reduction an effort should be made when molding the plaster to make a longitudinal groove separating the two bones.

Delay in union is common and refracture may occur in children while the original fracture is healing.

Open reduction and accurate fixation in the anatomic position, by

plate in the radial fracture and by intramedullary pin in the ulnar fracture, is far more important in adults than in children. Plaster should immobilize the joint above and below the fracture site. As a rule roentgenographic and clinical evidence of partial union will be attained in about 6 weeks, but immobilization should be continued for another 6 weeks.

One complication with this type of fracture is a Volkmann's contracture. Carefully watching the radial pulse and frequent observance of the swollen tense forearm will allow one to avoid this tragic consequence.

Volkmann's Contracture or Ischemic Paralysis

In 1875 Richard von Volkmann described contracture of a limb with paralysis due to or following the treatment of fractures with splints or dressings that were too tight. He believed that it was due to the shutting off of the blood supply and obstruction of the venous outflow. The forearm has been the most frequent site of this complication, the anatomic structure of the forearm making it particularly susceptible to the development of this syndrome. It may be associated with a supracondylar fracture or fracture of both bones of the forearm, accompanied either by contusions or by incomplete laceration of one of the large arteries. This produces a traumatic excitation of the periarterial sympathetic plexus. The pressure produced in the tight envelope of investing fascia of the forearm is a factor as well as the neurogenic and circulatory disturbances. The envelope of investing fascia becomes tense from the pressure of the hemorrhages within. The pathologic changes within, with or without tight external splints or dressings, *provide the basic underlying factors. Immediate loss of function in the* hand by this circulatory impairment is followed by contracture of the wrist and fingers, which gives rise to a very serious condition, the *main-en-griffe* deformity (Fig. 213).

The trauma produced in some cases of supracondylar fracture is caused by the sharp lower margin of the proximal humeral fragment which may injure the brachialis anticus muscle and brachial artery (see Fig. 191). The swelling can and should be lessened by early accurate reduction of the displaced fragments, as this alone lessens the probability of the development of a Volkmann's contracture.

Clinical Picture. There is definitely some obstruction to venous outflow and the painfully swollen elbow and forearm with the cold anesthetic hand and the absent radial pulse are characteristic features in

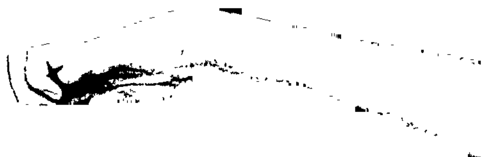


FIGURE 213. Volkmann's contracture. Note flat palm and sharply flexed interphalangeal joints with atrophy of forearm.

the early stages. Later the muscles become ischemic and are replaced in large part by islands of necrosis and scar tissue.

The cases with elbow or forearm fractures should be watched very carefully and if they denote an impending Volkmann's contracture, immediate operation is necessary. Unfortunately, the cases are not usually recognized early. Some of them may develop collateral circulation through the recurrent radial and ulnar arteries by simple elevation and permit a re-establishment of the radial pulse. There is great danger in waiting for this hoped-for happy outcome and therefore an immediate operation is advised.

Treatment. In the acute case treatment consists in an incision made through the deep fascia at the antecubital fossa to relieve the intrinsic pressure on the vessels. The median nerve and vessels should be examined. If the bone fragments are found to be exerting direct pressure, reduction of the fragments can be gently attempted. The operation should be done within a few hours after injury and is done primarily to relieve tension in the anterior compartment of the forearm. The skin only is loosely sutured and elevation continued.

In chronic cases in which the very disabling *main-en-griffe* deformity has developed, with flexion contracture at the wrist and fingers and fibrotic contractions of the tendons of the forearm, any attempt to get a return of satisfactory function usually falls far short of achievement. Many plastic operations on the muscles have been used as well as bone shortening procedures on the forearm, even excision of the carpal bones, but the prognosis in the last analysis must depend upon the residual muscle function.

Many times slow, gradual stretching of the contractures at the fingers, hand and wrist in the order named may, after months of effort, give a

great improvement but not, by any means, a restoration of normal function.

Ischemic contractures have been reported in the lower limbs but these are rare.

Madelung's Deformity (Subluxation of the Wrist)

Madelung's deformity (Fig. 214) is an uncommon condition appearing in late childhood or early adolescence following trauma or



FIGURE 214. Madelung's deformity.

without known cause. It is frequently bilateral and apparently represents a local nutritional or growth disturbance The lower portion of the radial shaft gradually bows forward, this deformity being accompanied by a change at the lower radioulnar joint so that the styloid process of the ulna becomes prominent. There is also increased relaxation at the distal radioulnar articulation, thereby diminishing the range of dorsiflexion and rotation of the forearm (Anton *et al.*, 1938).

The patient complains of a feeling of weakness and insecurity of the wrist as well as deformity.

Treatment. In the very mild types of deformity, simple strapping of the wrist on a cockup splint with a pressure pad over the prominence of the styloid process of the ulna is of value; but in the severe cases, excision of the lower end of the ulna and osteotomy of the bowed radius produces a greatly improved cosmetic appearance and restores function. (Hucherson, 1941)

Congenital Radioulnar Synostosis

This is a rare finding and is usually bilateral. The radius and ulna are found fused together, frequently at the proximal end, and this results in loss of forearm rotation with the forearm fixed in pronation. Two types have been described: (1) the true synostosis (Fig. 215),



FIGURE 215. *Left*, congenital synostosis of the forearm *Right*, congenital absence of left radius.

in which the upper end of the radius is fused to the ulna for a distance; and (2) the synostosis in which the radius is dislocated forward or backward, but is fairly well formed and is fused to the proximal ulnar shaft.

It is to be remembered that faulty muscular development accompanies the bony anomalies; therefore, the restoration of function is limited to the degree of motor power available.

Treatment. Excision of the synostosis and removal of the radial head, with fascia or metallic material interposed between the raw bony surfaces, must be done and the forearm placed in supination.

Congenital Absence of Radius or Ulna

Congenital absence of the radius (Fig. 215) or ulna occasionally is seen. When the radius is absent, there is a compensatory thickening of the ulna with the hand and carpal bones displaced toward the radial side of the wrist; operative correction should be delayed until the child is at least two years of age. Preoperatively, plaster can be used to stretch the contracted tissues and prepare for operative correction later.

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8

The Wrist and Hand

The Wrist Joint

APPLIED ANATOMY

The radiocarpal joint is of the condyloid variety. It consists proximally of a receiving cavity, which is oval and concave, composed of the lower articular surface of the radius and the triangular cartilage, which runs transversely and inserts into the intercondylar notch at the lower end of the ulna. This cartilage separates the ulna from participation in the wrist joint proper. The condylar area of the lower radial concavity has opposed to it the three bones of the first row of the carpals: the scaphoid (navicular), semilunar (lunate) and cuneiform (triquetrum) bones. The ligaments of the wrist joint are simple thickenings of the capsule on its four sides, and the joint is lined by synovial membrane. A great deal of the strength of the joint is derived from the strong flexor and extensor tendons which are tightly applied to the bone structure by the volar and dorsal carpal ligaments. Because of the gliding motion from the numerous bones that enter into the carpal groups, the wrist joint often escapes injury.

Epiphyses. The lower end of the radius appears in the first year and the ulna in the seventh year; both fuse about the twentieth year. The small bones of the wrist are cartilaginous at birth, appearing in the following order: first year, capitate; second year, hamate; third year, triquetrum; fourth year, lunate; fifth year, navicular; sixth year, multangulum major; seventh year, multangulum minor and tenth year, pisiform (Fig. 216).

The wrist is the site of (1) soft tissue injuries, such as sprains and injuries to the tendons, tendon sheaths and ligaments; (2) injuries to the osseous tissue, such as fracture to the scaphoid and dislocation of

the semilunar bone; and (3) in children epiphyseal separation of the lower end of the radius, all of which may occur through a fall on the outstretched hand. These injuries may or may not be complicated by other fractures, such as fracture of one or both bones of the forearm or of other carpal bones.

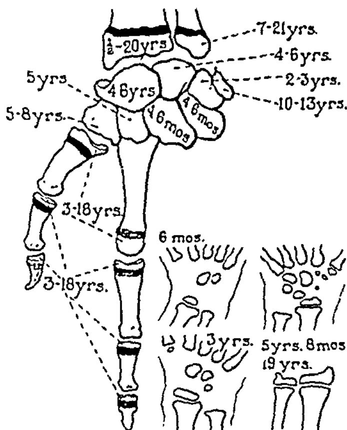


FIGURE 216. Ages at which appearance and fusion of epiphyses of wrist and hand occur.

The motions of the radiocarpal and midcarpal joints should be considered together. This latter joint has a double S-like curve, the capitate and hamate fitting into the concavity of the triangular, lunate and navicular bones, while the projecting navicular articulates with the multangulars. All motions of the hand on the forearm are compound, involving movements of the radiocarpal and intercarpal joints. Flexion and extension from the neutral position are derived initially from the radiocarpal joint, whereas the extremes of motion involve participation of the midcarpal joints Abduction (radial deviation) and adduction (ulnar deviation) of the hand also originate from motion of both joints.

When subject to trauma or disease the wrist should be maintained in the functional position of extension unless the alignment of fracture

fragments or the repair of a tendon or nerve requires the flexed position. In any painful state the wrist joint is instinctively flexed to reduce capsular tension, while gravity also encourages a wrist drop. A flexion contracture of the wrist joint not only results in a weakened grasp, but also causes contractures of the fingers. In this attitude the stretched long extensor tendons cause hyperextension at the metacarpophalangeal joints and secondary flexion contractures of the interphalangeal joints, resulting in a claw hand.

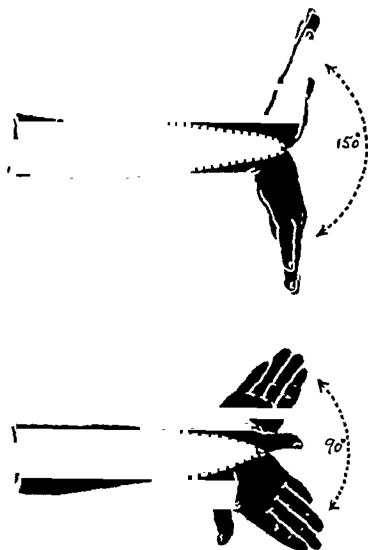


FIGURE 217. *Upper*, normal dorsal range and plantar flexion at the wrist joint. *Lower*, normal range of radial and ulnar deviation at wrist in young adults.

The hand in young adults can normally be *flexed to* about *100* degrees on the forearm and extended to about 250 degrees, and the range in ulnar and radial deviation will total about 90 degrees (Fig. 217).

Aspiration of the wrist joint is rarely necessary, but the method of inserting the needle dorsally into the joint space between the carpal and forearm bones is shown in Figure 218.

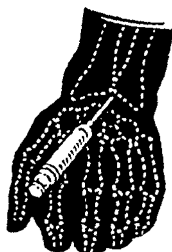


FIGURE 218. Method of aspirating wrist joint.

DISEASES

Tuberculosis

The wrist joint is rarely the seat of a tuberculous infection. Whitman (1930) states that in 3105 cases of joint tuberculosis seen at the Hospital for the Ruptured and Crippled, tuberculous disease of the wrist joint was found in children in only four instances. When it does occur, the disease usually starts in the radius or one of the carpal bones and rapidly spreads to involve the entire wrist. Abscesses which rupture give rise to multiple sinuses. A complete discussion of the pathology of joint tuberculosis may be found in Chapter 2 (p. 45).

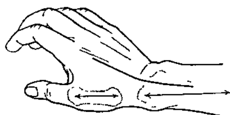
Clinical Picture. Stiffness progressing to serious limitation in motion, swelling, muscle spasm and a fusiform appearance at the wrist, with muscle atrophy proximally and distally, are characteristic of tuberculosis of the wrist joint. There is a flexion deformity at the wrist and usually some ulnar deviation of the hand, with pain on movement not only in the wrist joint, but also in the fingers. In the later stages of the disease, tuberculosis of the wrist can hardly be confused with any other condition, but in the early stages any type of acute arthritis, osteomyelitis of the carpal bones, and even chronic tenosynovitis must be considered in the differential diagnosis. Early in the disease there is atrophy of the bones of the wrist; later, destruction and blurred bony outlines without any evidence of bone repair are

characteristic roentgenographic features (Fig. 219A). This, taken in conjunction with the clinical history of wrist disability, makes tuberculosis the likely diagnosis, although a biopsy may sometimes be necessary.

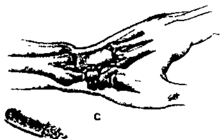
Tuberculosis of the wrist is complicated in many instances by multiple draining sinuses.



A



B



C

FIGURE 219. *A*, tuberculosis of wrist joint. *B*, lines of incision and position of wrist for wrist fusion. *C*, rib bone graft and bone chips in position for wrist fusion.

Treatment. Early immobilization of the wrist in a slightly cocked-up attitude permits rest, and if ankylosis occurs, this is the optimum position. Antibiotic therapy should be begun early, and those cases so treated in childhood have a good opportunity for restoration of a good deal of wrist function.

In children, a snug plaster splint gives almost complete immobilization of the wrist joint, but the plaster should be trimmed to allow movement at the metacarpophalangeal and interphalangeal joints and should extend to the elbow. It is a tragedy when tuberculosis of the wrist is treated by immobilization in plaster with the fingers extended.

In the adolescent and adult, arthrodesis of the wrist in the cockup position, using a tibial or, better still, a rib or iliac graft (Fig. 219B, C), permits arrest of the tuberculosis and results in a painless stiff wrist. In the adolescent or adult, if the disease is confined to one or two carpal bones, complete excision of these bones may be desirable. When the disease is widespread, surgical fusion of the joint is recommended. In the adult, many cases are complicated by pulmonary tuberculosis; for these patients the prognosis as to life is bad. Amputation in the late cases may be necessary. Drug therapy should be routinely employed; sinuses show a pronounced tendency to close after its administration.

Tuberculosis of the Tendon Sheaths. Tuberculosis of any of the tendon sheaths about the wrist joint is also seen, although the flexor sheaths are most commonly involved. The synovial lining of the sheath becomes thickened with granulation tissue and late in the disease, fluid and rice bodies are encountered. The tendon itself is not involved until late in the course of the disease.

The onset is slow and the patient may first note only stiffening of the involved tendons. Later the tendons thicken and become painful on motion. A palpable mass is felt along the course of the tendons and crepitus may be elicited at certain stages of the disease. Tuberculous tenosynovitis must be differentiated from villonodular synovitis or giant-cell tumor of the tendon sheath, as well as the nodular tenosynovitis frequently seen as the presenting sign of rheumatoid arthritis.

Specific antibacterial therapy is begun, following which the involved sheath is widely resected. Usually the tendon surface is found to be uninvolved after the granulation tissue is removed, although on occasions it is included in the disease process, in which case the tendon also requires resection. Antibacterial therapy and splinting in the position

of function is continued postoperatively until the disease process subsides.

Osteomyelitis

Osteomyelitis of nontuberculous origin is very rarely seen in the wrist. It may be produced by many organisms, such as staphylococci, streptococci, pneumococci, and even blastomycetes and actinomyces. The pathologic picture of osteomyelitis is discussed in Chapter 2, page 54.

Clinical Picture. Osteomyelitis has the characteristic appearance of an acute infection, i.e., pain, tenderness, swelling, redness and local heat. In the chronic stage these infections may somewhat resemble tuberculosis; however, roentgenograms do not show the same degree of bone destruction; on the contrary, they reveal some evidence of bone production. The bones may become atrophic, but they retain more of their articular detail.

Treatment. Usually surgical drainage, isolation of the organism, and suitable chemotherapy with immobilization in the optimal cockup position are followed by healing and limited function.

Prognosis. The prognosis for ultimate function is better in nontuberculous infection than in tuberculous infection.

Ganglia

Ganglia are cystic types of tumors, or swellings, occurring about a joint or tendon sheath. The dorsal surface of the wrist is most commonly involved (Fig. 220). The tumors contain a gelatinous mucoid substance and the wall of the sac is lined with synovial tissue and a fibrous capsule which is sometimes lobulated and may be attached to the tendon sheath. They may develop after an injury, such as a sprain,

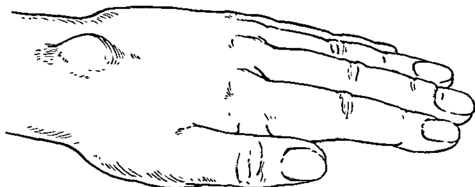


FIGURE 220. Common location of ganglia.

or without any known trauma. Some authorities consider them herniations of the synovial membrane through a weakened area in the tendon sheath, with colloid degeneration of the synovial membrane.

Treatment. These tumors will on occasion spontaneously disappear or, on the other hand, grow to proportions large enough to cause functional disability and pain. The only acceptable method of treatment is thorough, complete excision of the sac down to its base whether it be tendon sheath or joint. Even after careful removal, recurrences may be seen. Aspiration of the contents of the cyst through a large bore needle will reduce the size of the tumor, but only excision of the sac can result in cure.

SOFT TISSUE INJURIES

Strains of the Wrist

Strains may follow unusual or repetitive activity and may even give rise to a tenosynovitis or inflammation of the tendon sheaths about the wrist. This may be infectious, traumatic or toxic in origin.

The diagnosis of this condition is most easily made by resting the palm of the examiner's hand flat against the flexor or extensor surface of the forearm. On movement of the patient's hand a peculiar characteristic grating sensation is felt as the tendons glide in their sheaths. Tenderness is also noted along the course of the involved tendon and stress against the tendon produces pain.

Treatment. If the condition is acute, following some occupational cause or direct injury, the injection of procaine or Hydrocortone or both, followed by strapping the wrist or putting the joint at rest on a molded plaster splint for a few days or weeks and by baking and massage, may be all that is necessary to relieve the condition and the pain. If, however, the tenosynovitis becomes chronic, further investigation to rule out a tenosynovitis related to rheumatoid arthritis or tuberculosis should be considered.

De Quervain's Disease (Stenosing Tenosynovitis; Stenosing Tendovaginitis)

De Quervain's disease is a common condition seen more often in females and affects the common sheath of the abductor pollicis longus and extensor pollicis brevis tendons as they pass through the groove in the radial styloid process. The sheath thickens at this point and is firmly bound to the styloid process. The mesotendon develops an in-

flammatory reaction and an increase in fluid results. This condition is thought to result from repeated activity of the thumb, such as in knitting, sewing, or using shears. However, it occasionally seems to follow a single definite trauma. The patient complains of pain on use of the thumb and wrist.

Extreme tenderness and slight swelling is almost always present over the radial styloid process (Fig. 221). Use of the long abductor and



FIGURE 221. Quervain's disease, showing point of exquisite tenderness near styloid process of radius.

short extensor muscles of the thumb elicits pain referable to the radial styloid region, which is increased when resistance is offered to these tendons. When the thumb is flexed across the palm of the hand and the wrist slowly moved into ulnar deviation, severe pain is felt over the radial styloid process.

Treatment. The injection of Hydrocortone into the area of the radial styloid process usually results in relief of symptoms. Pain and disability often recur, however, and a second injection may be advisable. If relief is incomplete, the simple operation of dividing the sheath at the thickened portion should not be delayed too long as the results are excellent and recurrences rare. Anomalous tendon distribution is frequently found within the involved sheath, the most common abnormality being duplication of the long abductor tendon to the thumb. The smaller short extensor thumb tendon may course through a sep-

arate compartment and should be sought and identified and not confused with the duplicated long abductor tendon. The operation can be done under local anesthesia, and early postoperative movement of the thumb is desirable.

FRACTURES

Colles' Fracture

Abraham Colles in 1814 described for the first time the injury that now bears his name. It is a fracture of the lower end of the radius within 1 inch of the articular surface, common in adults but unusual in children. The fracture results from a fall on the dorsiflexed hand, causing the lower fragment of the radius to be displaced backward with upward tilting of its articular surface; the radius is thus shortened (Fig. 222). This causes a change in the relative position of the styloid

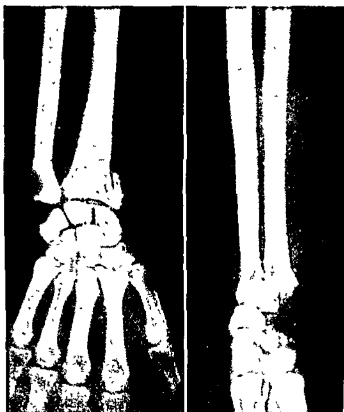


FIGURE 222. Typical Colles' fracture Note backward tilting of radio-articular surface, fracture of styloid process of ulna and shortening of radius.

processes of the ulna and radius. Frequently the fracture of the radius is complicated by the tip of the ulnar styloid process being torn off. The wrist assumes the "silver fork" deformity.

The role of the triangular cartilage of the wrist joint, which runs from the edge of the sigmoid cavity to the notch between the head and styloid process of the ulna, is important in Colles' fracture. In normal rotation of the forearm, the ulna plays a passive role, serving as a fixed point about which the radius moves. The two long bones of the forearm must be maintained in secure apposition during the motion of rotation. In severe fractures about the wrist the ligaments and cartilage may be ruptured or torn. In these cases the ulnar head becomes more prominent on the volar aspect of the wrist and is abnormally movable. In elderly individuals severe comminution of the lower fragment extending into the joint is seen and presents a most difficult problem in the maintenance of reduction. Prompt reduction of the broken radial fragments and restoration of the normal ulna-radius relationship are necessary.

Clinical Picture. The deformity mentioned above and the immediate disability are the characteristic features. Swelling of the hand and wrist quickly follows the injury. When there is little or no displacement, local tenderness and history of a fall on the outstretched hand should be regarded as indicating a fracture, unless the roentgenogram is definitely negative.

Treatment. *Manipulative reduction* usually provides satisfactory results in these cases. A careful study of the roentgenograms before reduction is attempted is essential. Reduction must be aimed at promptly restoring the normal anterior tilt to the lower articular surface of the radius and restoring the normal relationship of the styloid processes of the two bones, so that the tip of the radial styloid process is at its normal level, slightly more distal than the ulnar styloid. The ulna must also be brought into close apposition at the inferior radio-ulnar joint to expect a complete restoration of function.

Under local or general anesthesia, longitudinal traction should be applied to the fingers and thumb with countertraction at the flexed elbow while at the same time direct pressure is made over the displaced distal fragment Displacement of the distal radial fragment is usually corrected by a twisting or rocking movement. Hyperextension of the fragments may be applied to unlock the fragments, followed by forced flexion. A sugar-tong splint, enclosing the elbow and lightly padded, is covered by a snug gauze bandage and then molded closely to the skin while the wrist is held in slight flexion and ulnar deviation —Cotton-Loder position (Fig. 223). Roentgenograms taken after reduction will show whether the fracture has been properly reduced.

Special care must be taken to restore the normal volar tilt to the articular surface of the radius and to check the radial pulse after the plaster has been applied. Cut a small trap door in the plaster for this. The fingers and metacarpophalangeal joints must be left free, and

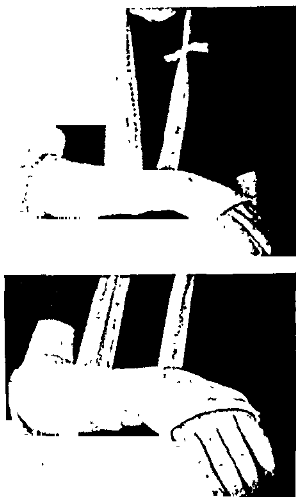


FIGURE 223. Type of plaster cast used for immobilization after reduction of typical Colles' fracture, without comminution, at the wrist. The cast is cut out in the palm to permit flexion of the fingers and thumb. Note slight flexion and adduction of hand at the wrist. (Key and Conwell, *Fractures, Dislocations, and Sprains*, C. V. Mosby Co., 1956.)

immobilization continued from 4 to 6 weeks, depending on the severity of the original displacement and comminution. As the soft tissue swelling subsides the splint should be rewrapped more securely; otherwise the position will not be maintained. Physical therapy and occupational therapy hasten convalescence after the splints have been removed.

Directly after reduction the motion of the fingers should be carefully observed. If swelling and inability to move the fingers persists,

the wrapping may require loosening, and if pain, swelling and loss of finger function continue, it is probably wiser to reduce the amount of wrist flexion in order to improve the circulation, even at the risk of losing a part of the reduction. Wrist function subserves finger function and a well-aligned wrist with stiff fingers is to be avoided.

In a severe comminuted type of Colles' fracture, skeletal traction by the use of Kirschner wires passed transversely through the second, third and fourth metacarpal shafts with countertraction through the olecranon may be necessary to obtain closed reduction. Adequate molding of the several fragments may then be done before immobilizing the wrist in plaster of Paris.

Open reduction is rarely necessary in fresh Colles' fractures but may be required if attempts at closed reduction are unsuccessful.

Complications. (1) Occasionally a Colles' fracture produced by a fall on the outstretched hand causes contusion or fracture of the articular surfaces of the shoulder joint. Certain patients may consequently develop a stiff shoulder several weeks after the original Colles' fracture, so that the shoulder should be routinely examined and early active circumduction shoulder exercises begun at once.

(2) The small finger joints stiffen quickly following swelling and should be carefully observed. Elevation, proper tension of the bandages and avoidance of an unduly flexed position of the wrist are important.

(3) Spontaneous rupture of the extensor pollicis longus tendon has developed a number of times following a fracture of the lower end of the radius, usually a Colles' fracture. Also, a late rupture of the flexor pollicis longus tendon has occurred by the same mechanism. This complication would appear to be due to movement of the affected tendon over a spicule of bone at the fracture site, producing a wearing away or fraying of the tendon as it moves back and forth in its radial groove. Forceful manipulation at the time of the reduction plus trauma at the time of fracture might cause an interference to the local blood supply to the tendon via the mesotendon, producing an avascular necrosis and later dissolution of tendon continuity. Treatment consisting of fastening the distal end of the extensor pollicis longus to the extensor indicis proprius or radial wrist extensor by an end-to-end suture has been reported as giving satisfactory results (Smith, 1946).

(4) The possible complication of an accompanying fracture of the carpal scaphoid must be kept in mind.

Prognosis. In Colles' fractures the prognosis for restoration of function depends on the degree of comminution, the proper reduction, the

age of the patient and the constant active early use of the fingers and shoulder joint. Adequate immobilization of the fracture must be maintained until there is roentgenographic evidence of solid union.

Smith's Fracture (Reverse Colles' Fracture)

This is a rare injury and grossly resembles a plantar carpal dislocation. Roentgenograms (Fig. 224) reveal a fracture of the radius, often comminuted in the lower cancellous portion with avulsion of the ulnar styloid process. Frequently, but not always, it occurs as a consequence of a fall on the back of the hand.



FIGURE 224. Smith's fracture of wrist (a reverse Colles' fracture).

Treatment consists of reverse manipulation to that used in reducing a Colles' fracture. It is difficult to maintain the reduction but full supination, with plaster extending from metacarpophalangeal joints to above the elbow and with the wrist in slight flexion, should be maintained for 6 weeks.

Barton's Fracture

Fracture of the posterior articular margin of the radius occasionally occurs, with upward and backward displacement and with some tend-

ency to subluxation at the radioulnar joint. Only in oblique roentgenograms may this fracture be obvious. This is sometimes regarded as one type of so-called "chauffeur's fracture," a name which arose from fractures caused by the backfiring while cranking the outmoded type of automobile.

Treatment. Either with a general or local anesthetic, the displaced fragment should be replaced by firm direct pressure. If left untreated, the extensor pollicis longus tendon may be injured by the movement of the sharp marginal projection of the fragment. To prevent this, the wrist, after reducion of the fracture, is immobilized in plaster in dorsiflexion; this position is also a safeguard against subluxation backward of the proximal row of carpal bones. After 3 weeks the wrist is placed in a straight position in a light plaster for a few weeks longer and then all support is discontinued.

Separation of Lower Radial Epiphysis

Separation of the lower radial epiphysis is a common injury in childhood and adolescence and is produced by a fall on the outstretched hand. The epiphysis is displaced posteriorly, usually taking a small chip of the diaphysis from the dorsal surface. Rarely is the epiphysis alone displaced, and roentgenograms should always be studied to decide between the types with and without fracture.

Treatment. Reduction should be done as early as possible for healing between displaced fragments occurs rapidly. Always check with post-reduction films (Fig. 225) as early as possible.

If manipulated early, strong traction and thumb pressure on the displaced epiphysis permits reduction. Plaster applied with the wrist in sharp flexion permits the taut extensor tendons to aid in keeping the epiphysis reduced. A few weeks of immobilization is all that is necessary.

Even if seen late, it is rarely wise to attempt open reduction. Growth disturbances are more frequent following the degree of trauma necessary to effect open reduction at the site of malunion. Excellent function often results even in the malunited cases, for in a few years the molding forces of nature may produce a remarkable restoration of the normal bony pattern.

Occasionally, as a late complication, growth disturbance in the lower end of the radius causes an arrest of growth, with shortening of the radius, radial deviation of the hand and decrease in the grip. All patients should be warned against this possible complication.



FIGURE 225. Separation of the lower radial epiphysis. *Upper,* before reduction; *lower,* after reduction.

Fractures of the Carpal Scaphoid (Navicular)

Before the advent of roentgenograms, fractures of the carpal scaphoid were rarely recognized, but it has since been found to be one of the most common of the carpal injuries, and is seen most frequently in the young adult male.

This fracture is generally caused by a fall on the outstretched hand either in radial or ulnar deviation, the force of which is transmitted to and through the metacarpals to the scaphoid and semilunar bones. This is also the mechanism by which a Colles' fracture is produced, so that both of these injuries may occur simultaneously. Rarely is the scaphoid fractured by direct violence.

The vascular supply of the scaphoid is tenuous due to its large intra-articular cartilage-covered surface area Most of its blood supply, therefore, enters the distal half of the bone through the joint capsule. Small fractures through the proximal portion of the bone are deprived of circulation and heal more slowly than fractures through the distal portion of the bone.

Clinical Picture. The clinical features are swelling of the joint, especially in the region of the anatomic "snuffbox," with local sensitiveness at this point. When this bone is fractured, pressure against the head of the second metacarpal, with the fingers flexed, will frequently cause pain in the region of the scaphoid. Movement of the wrist, particularly in radial deviation, aggravates the pain. Fracture must always be suspected in those cases with local tenderness, even with negative findings by roentgenogram. Anteroposterior, lateral and *oblique* views (Fig. 226) should be insisted upon in suspected cases and if the

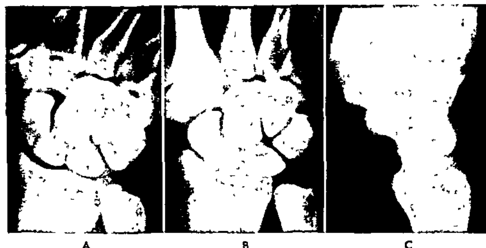


FIGURE 226. Incomplete fracture of scaphoid. *A*, oblique view of wrist shows fracture. Not seen in *B* or *C*. *B*, anteroposterior view of wrist; *C*, lateral view of wrist.

clinical picture points to a fracture, despite negative roentgen findings, they should be repeated in several weeks, the hand meanwhile being immobilized. Sometimes an incomplete fracture is very difficult to recognize on the original roentgen films, but after a few weeks the fracture will undergo bone absorption and demonstrate a line of fracture or cystic degeneration of the bone at the site of fracture.

Prognosis. With the troops in World War II, bony union in this type of fracture was obtained much more often than in civil practice because immobilization was insisted upon for a longer period of time and also because the fractures were in young healthy adults

It is believed that if the fracture can be adequately treated within the first few days, in the young adult, bony union may be expected in 90 per cent of the uncomplicated scaphoid fractures. This high rate of union depends upon early diagnosis and prompt, effective, continuous and persistent immobilization

Treatment. Treatment of recent scaphoid fractures without displacement of the fragments is by long-continued immobilization of the wrist, including the interphalangeal joint of the thumb, with the hand in a slight radial and dorsiflexed position (Fig. 227). This immobiliza-



FIGURE 227 For clarification in suspected scaphoid fracture, take two anteroposterior roentgenograms with hand forcibly deviated (*left*) radially and (*right*) ulnaward

tion (Fig 228) must be continued from 8 to 12 weeks or *longer*. A safer procedure is to immobilize until bony union at the site of the fracture can be demonstrated by the roentgen film.

In fracture with gross displacement, an open reduction and insertion of a bone graft to maintain reduction is advisable.

Nonunion of the scaphoid. It must be remembered that union is always slow and that many times an apparent nonunion can be converted into firm, solid union by further immobilization of the hand and wrist (see Fig 104, Chapter 2). One may even immobilize the region 6 months before concluding that nonunion will be the result. In definite nonunion in a young individual, complete excision of the fragments or drilling of the fragments and/or bone grafting with a

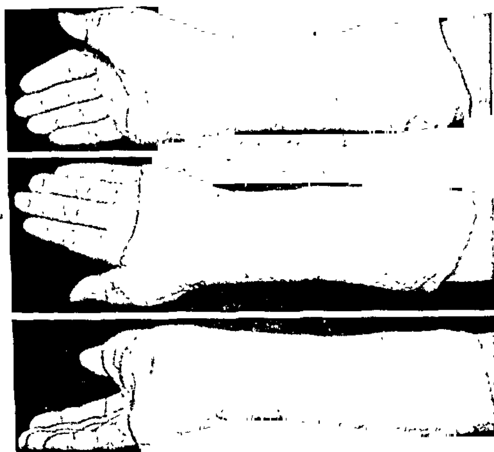


FIGURE 228. Plaster encasement for fracture of carpal scaphoid: *Top*, ventral; *center*, dorsal; *bottom*, oblique. Note molding to palm and forearm, upper and lower limits, moderate "grasp" position of wrist, and inclusion of abducted proximal phalanx of thumb. (Bancroft & Murray, *Surgical Treatment of the Motor-Skeletal System*, J. B. Lippincott Co. Phila., 1945.)

match type of bone graft are three surgical methods commonly employed, the last being the most desirable. It is surprising how much function, however, will develop without surgical interference in an occasional case of frank nonunion; a patient may carry on for years with roentgenographic evidence of nonunion without much trouble.

Preiser's Disease. This is an avascular necrosis of the scaphoid following injury to the wrist. The joint may remain very tender, weak and painful, and more or less swollen. A moderate amount of tenderness can be elicited on pressure over the scaphoid. The wrist is weakened and patients will complain of a variable amount of pain. Roentgenograms (Fig. 229) show more density than normal or sclerosis of the bone. The wrist should be immobilized in the hope that revascularization may occur; if this fails to occur, excision of the bone is recommended.

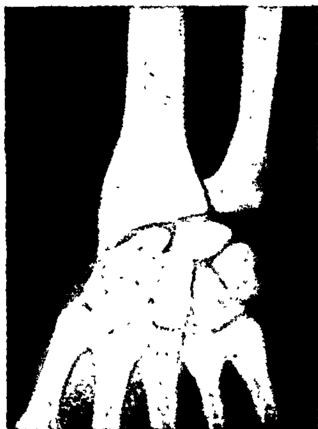


FIGURE 229. Avascular necrosis of the scaphoid. (Preiser's disease).

Fracture-dislocation of the Carpus

The navicular (scaphoid) bone, with its long axis parallel to the axis of the forearm, connects the proximal carpal row with the distal carpal row of bones. The proximal part of the navicular is firmly bound by ligaments to the lunate under the protecting buttress of the radius, whereas the distal portion of the navicular is bound firmly to the remainder of the carpus.

A severe dorsiflexion force will fracture the navicular and carry the distal navicular and the remainder of the carpus into a posterior dislocation in reference to the proximal navicular and lunate which remain in undisturbed relationship to the radius. This is known as a perilunar dislocation of the wrist with a fracture of the navicular. The anteroposterior roentgenograms are difficult to interpret, but do show a wide separation of the navicular fragments. Careful examination of the lateral roentgenograms (Fig. 226C) show the dislocation. Reduction is accomplished by flexion of the hand and treatment is then followed as for a navicular fracture, but the prognosis for union is not

as good as in uncomplicated navicular fractures. Avascular necrosis of the proximal fragment is also frequent in this injury.

Dislocation and Fracture of the Semilunar

Fractures of the semilunar alone are rare, but dislocation without fracture of the navicular or semilunar are more frequent (Wagner, 1956). The semilunar bone lies between the articular surface of the radius and the os magnum (capitatum), and when the hand is suddenly forced into dorsiflexion, forward dislocation of the bone may occur. In this instance the navicular stays with the remainder of the carpus which momentarily is displaced dorsally and then settles into its normal relationship with the radius as it forces the lunate volarward.

Clinical Picture. The clinical features are immobility of the semiflexed fingers, often with median nerve involvement due to contusion to the nerve; thickening and swelling of the soft tissues on the front of the wrist; and limitation of wrist motion. The head of the os magnum may sometimes be seen in direct contact with the radius, although the dislocation frequently is overlooked in the roentgenograms (Fig. 230).



FIGURE 230 Usual type of simple dislocation of carpal semilunar bone.

Prognosis. If reduction can be obtained gently shortly after the accident, full function of the wrist should be expected; but if it becomes necessary to remove the semilunar bone, some residual weakness and stiffness in the hand and wrist must be expected. In those older cases with evidence of hypertrophic arthritis in the other carpal bones, the prognosis for painless free motion is poor.

Treatment. Under local or general anesthesia, straight traction is applied. It should be constant and steady on the outstretched fingers, with the elbow flexed and countertraction exerted in the opposite direction. This permits the flexor tendons to aid in pushing the semilunar back into its position. Sometimes the semilunar can be gently manipulated into position by having the assistant give steady traction on the fingers while the operator presses with both of his thumbs over the front of the dislocated bone. In the old cases, and especially in the fresh cases in which the manipulative methods described failed to reduce the semilunar, open reduction with replacement may be advisable. In cases with evidence of gross degeneration or avascular necrosis of the bone (Kienböck's disease), complete removal is indicated, the incision being made on the palmar surface of the wrist.

Kienböck's Disease. This may follow an injury to the semilunar bone. The condition may develop months and even several years after the original injury. Apparently it may also appear without definite injury. Pathologically it represents an avascular necrosis. Roentgeno-



FIGURE 231. Avascular necrosis of the right semilunar bone (Kienbock's disease).

grams (Fig. 231) show a progressive sclerosis with rough edges and the bone may appear fragmented.

Conservative attempts to produce revascularization in both Preiser's disease and Kienböck's disease have not been particularly successful. Excision of the involved bone is the treatment of choice.

The Hand

APPLIED ANATOMY

The bones of the hand consist of the proximal and distal row of carpal bones, the five metacarpals and the fourteen phalanges. The latter consist of three rows of long bones making up the fingers, and the two phalanges composing the thumb. These bones are strongly bound together by ligamentous fibers and the joints are further strengthened by the thick strong tendon sheaths on the flexor and extensor surfaces. The hand is strengthened by both the extrinsic and intrinsic groups of muscles, the latter being subdivided into three groups, the thenar, the hypothenar, and those in the middle of the palm and between the interosseous spaces (Fig. 232).

Arching over the carpals on the flexor aspect is a strong fibrous anterior annular ligament beneath which pass the extrinsic or long flexor tendons to the fingers. This annular ligament is continuous above with the deep fascia of the forearm and below with the palmar fascia, and aids in binding down the flexor tendons; the same function is taken by the posterior annular ligament on the extensor surface of the wrist. The deep palmar fascia, which lies just underneath the skin and invests the muscles of the hand, is divided into a central and two lateral divisions. Parts of this or the entire palmar fascia may undergo contraction, producing the deformity called Dupuytren's contracture (p. 369). Distally the fascia is broad and expanded and divides into four pretendinous bands covering the flexor tendons of the second to fifth fingers.

The *lumbricales* are accessory muscles to the deep flexor group and insert into the radial aspect of the dorsal aponeurosis of the four fingers. Together with the interossei muscles, which also insert into the dorsal aponeurosis as well as the proximal phalanges, they act by producing flexion of the metacarpophalangeal joints and extension of the interphalangeal joints. The palmar interossei also adduct the fingers; the dorsal interossei abduct the fingers. The interossei, lumbricales,

thenar and hypothenar are known as the intrinsic muscles of the hand and paralysis or contracture of this group results in severe finger and thumb deformities. The intrinsic muscles of the hand, with the exception of the thenar group and the first and second lumbricales, are sup-

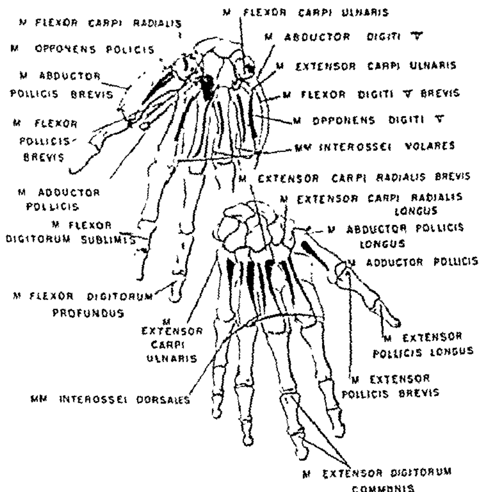


FIGURE 232 Carpal bones and hand showing muscle attachments. Red: muscle origin Blue muscle insertion

plied by the deep branch of the ulnar nerve. The thenar muscles are supplied by the recurrent branch of the median nerve. The first and second lumbricales are also innervated by branches of the median nerve.

The thumb is of primary importance, since opposition of the thumb to each of the four fingers, allowing pinch and dexterity in the handling of instruments and tools, provides the difference in function between man and the lower animals depending on prehension.

The ligaments of the metacarpophalangeal and interphalangeal joints are stable in flexion As the joints extend the ligaments relax. Edema

and scar tissue of the capsule incident to disease or injury will contract the capsule and prevent flexion if the joint is maintained in extension. On the other hand, a joint immobilized in flexion relaxes as it extends and such a joint usually will extend without difficulty after an inflammatory or traumatic episode.

The *fascial spaces* of the hand, which consist of the triangular midpalmar space, lying between the thenar and hypothenar eminences, and the thenar space, also triangular in shape, lying under the thenar group of muscles, are of great practical importance. There is a fascial area deep to the flexor tendons in the lower part of the forearm, which may become infected by extension from the synovial sheaths of the flexor tendons of the hand. In addition to this, the dorsal subcutaneous and dorsal subaponeurotic spaces are made up of loose areolar tissues which permit much more swelling on the dorsum than is permitted by the strong, compact palmar fascia. For this reason we find palmar infections causing dorsal swelling and obscuring the diagnosis. For a complete anatomic discussion consult any anatomy book.

THE CARE OF THE HAND

As the value of the hand depends upon both its strength and its dexterity, it is of the utmost importance that a restoration of form and function be meticulously sought in all injuries and infections. Treatment of hand disabilities requires the most careful attention to surgical detail, so that the reader is referred to special books on this subject, particularly that of Bunnell (1956).

The functional position of the hand is that of semiflexion of the fingers and opposition of the thumb. The transverse arch of the palm should be maintained. This can be accomplished by splinting on a convex surface rather than on a flat board.

In the injuries of the hand a careful examination is necessary, for it is in the emergency treatment that the future function of the hand may largely depend. One must be able not only to treat the open skin wound, but also to decide whether the tendons or nerves are intact. As soon as possible a roentgenogram should be taken to determine the type and extent of possible fracture or dislocation.

Wounds of the Hand. Wounds of the hand and fingers require early careful débridement. The specialized resistant, sensitive skin cannot be radically sacrificed and only devitalized areas should be removed. The underlying tissue, consisting of a compact mass of tendons, nerves,

thenar and hypothenar are known as the intrinsic muscles of the hand and paralysis or contracture of this group results in severe finger and thumb deformities. The intrinsic muscles of the hand, with the exception of the thenar group and the first and second lumbricales, are sup-

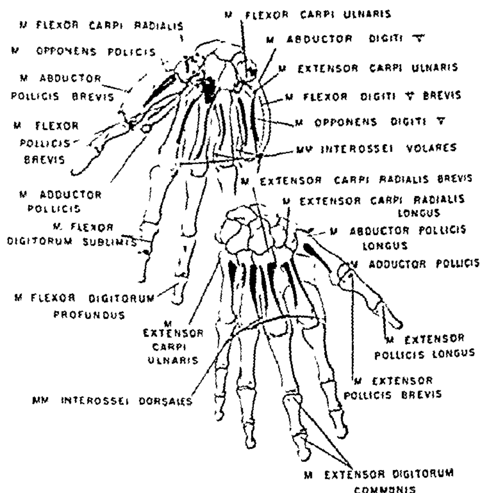


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DISEASES

Tuberculosis

Tuberculosis of the joints in the hand is rare. Figure 233 shows a proved case involving the second metacarpophalangeal joint. Tuberculosis dactylitis (spina ventosa) is not frequent also, but is more common than joint involvement.

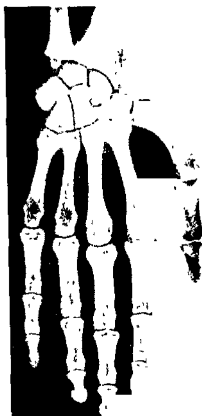


FIGURE 233. Tuberculosis of second metacarpophalangeal joint.

Tuberculosis Dactylitis (Spina Ventosa).* Tuberculosis dactylitis is usually a disease of *infancy or childhood and the adult form differs* from that found in children. The earliest roentgenographic evidence (Fig. 234) of both forms is the elevation of the periosteum with irregularity in the cortex. In children, the periostitis increases in thickness and expands the cortex. Destruction of the shaft occurs with sequestration, leaving a cystlike cavity which appears to be ballooned or injected with air. In the adult *form, the cortex becomes eroded and de*stroyed, giving a rather honeycomb appearance. Pathologic fracture is

* See Umansky *et al.* (1947).

vessels and important intrinsic muscles, should also be very conservatively treated. In injuries more than several hours old or in badly contaminated wounds no effort should be made to primarily repair tendons or nerves. Large areas of exposed tissue should be covered with skin to prevent scar tissue and adhesions; this may require a split-thickness graft. Large open drainage areas should be avoided. Fingers should not be removed at the time of débridement unless unequivocal evidence of circulation failure is present. Extensive trauma to bone structure and tendons is not in itself a cause for primary amputation. In particular, conservatism should be practised in preserving thumb tissue as the thumb is of such vital importance in hand function.

After closure of the wound an evenly distributed pressure dressing is applied, over which a splint is used to maintain the position of function. The early use of antibiotics is important to prevent the development of infection. Tetanus toxoid or antiserum should be administered and in certain puncture wounds favoring the development of anaerobic organisms gas antiserum should be given.

Repair of tendons and nerves may be done at the time of initial débridement if instant closure can be accomplished and contamination is not severe. Repair of flexor tendons in the fibrous sheath between the distal crease of the palm and the distal flexor crease of the finger is subject to adhesions and should rarely be done at the time of débridement.

The repair of tendons of the fingers and hand demands meticulous technic, using fine instruments and suture materials. The work should be done under pneumatic tourniquet control with adequate lighting, assistants, and in an unhurried manner. As none of these requisites are present in the accident ward of a busy hospital, secondary repair is wise.

When both flexor tendons to the finger are severed, it is necessary to repair the profundus tendon only, sacrificing the sublimis and removing it from the sheath so as to allow more room within this confined area for the profundus tendon. Repair of both tendons at the same level invariably results in a cross anastamosis. The repair of the profundus alone in the sheath area offers many problems and it is advisable to replace this tendon with a graft so that all suture lines will be outside the sheath area Another alternative is to resect a limited portion of the sheath in proximity to the anastamosis. After repair the finger should be splinted in flexion for 3 weeks before motion is begun.

diagnosis. It is believed that the prognosis is better in children, and many of these lesions heal spontaneously.

Treatment. In the adult form of dactylitis, amputation of the affected finger is generally necessary. The amputation should be proximal to the metacarpophalangeal joint so that the remaining metacarpals can be drawn close together, giving a satisfactory cosmetic appearance.

Paronychia

Paronychia is an infection, superficial or deep, about the base of the nail, commonly called a "runaround." The infection often starts when a hangnail is pulled out or may follow a pin or needle prick. The pathologic process begins at one side and gradually extends around the periphery of the nail as the infection spreads above and below the nail (Fig. 235).



FIGURE 235. The common "runaround" (paronychia). The tissues around the periphery of the nail become swollen, inflamed and painful.

Clinical Picture. A swollen, exquisitely tender, reddened and obviously infected area about the base and around the periphery of the nail is seen, and, if neglected, results in destruction of the nail matrix with distortion in the subsequent growth of the nail bed

Treatment. The treatment is surgical in all but the mildest cases. These mild cases may respond to constant hot soaks and elevation, but even in these surgery often is necessary.

A most satisfactory technic for the well-developed paronychia is as follows: An elastic tourniquet is placed about the base of the finger after instituting a nerve block to the digital nerves with 1 per cent procaine, general anesthesia is not usually necessary. Two slightly diver-

sometimes seen, but there are no large sequestra or involucra and no fistula formation, as noted sometimes in younger patients.



FIGURE 234. Spina ventosa involving second and fourth metacarpal bones.

Osteomyelitis

Osteomyelitis of the metacarpals and phalanges follows the usual course of a bone infection (see Chapter 2). Because the function of the hand is dependent upon its mobility and dexterity, the limitation of motion that accompanies osteomyelitis and soft tissue involvement makes infection particularly disabling. If the infection is massive, the prognosis for restoration of function is poor.

Treatment. Chemotherapy as well as adequate incision and drainage are essential and the hand should be supported in the semiflexed, never a flat position on a splint

Syphilitic Dactylitis

Syphilitic dactylitis may be confused with other forms of osteomyelitis, but in the luetic patient the bone has greater density and less evidence of necrosis; evidence of syphilis elsewhere aids in making the

upon the flexor surface of the hand are the most important. Figure 236 illustrates the location of the various sheaths and the incisions necessary to give adequate drainage. On the dorsum of the hand the sheaths are less extensive; however, an infection here can also rupture into the adjacent fascial spaces of the palm.

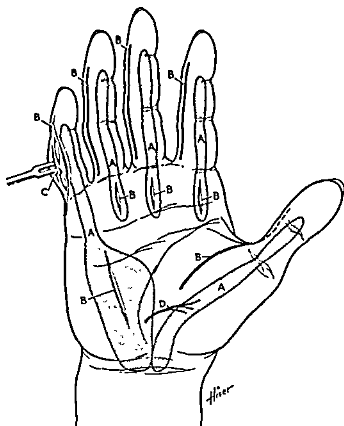


FIGURE 236. *A*, anatomic distribution of flexor tendon sheaths. *B*, elective skin incisions for draining tendon sheath infections. On fingers incisions should be posteromedial or posterolateral. Note (*C*) that island of tendon sheaths should be preserved at flexion creases. Incision should not be prolonged to injure branches of ulnar nerve (*D*).

With streptococcus and staphylococcus, the infection is commonly an acute one, and the viability of the tendon is always threatened if the patient is not treated promptly.

A puncture wound in the pulp of the finger may not only cause a local infection but may easily extend across the thin membrane constituting the terminus of the flexor tendon sheath. Streptococcic infection may spread up into the finger or hand in only a few hours; although the staphylococcus spreads more slowly, local distention of the tissues with exquisite pain and tenderness is the rule. Kanavel (1939) has shown conclusively the pathway these infections of the hand follow.

gent incisions are made on either side at the base of the nail so that the flap has a broad base to insure its blood supply, and the flap is then loosened, exposing the nail bed. The proximal portion of the nail may be completely removed by a twisting motion which extracts it from the nail bed. A small narrow strip of packing is then placed under the skin flap and fluff gauze placed over the finger, which is loosely bandaged into position. Wet soaks are continued until the packing is removed on the third day, when the finger is more snugly bandaged. The use of penicillin and/or sulfonamides should be combined with surgery.

Felon

A felon or whitlow is an acute inflammation of the distal closed pulp space on the front of the distal phalanx. It may be infected by needle, pinprick or scratch. The acute inflammatory reaction may develop very rapidly, and a severe throbbing pain is usually the first evidence of a developing felon.

Clinical Picture. This is an acute infection confined to the terminal phalanx which becomes swollen, tender and tense with exquisite pain. As this is a closed space in the pulp region of the finger, early relief of the tension is essential. To delay is to prolong the pain and to hasten the opportunity for the underlying bone to become involved in an acute osteomyelitis. If the infection ruptures into the flexor tendon sheath, a severe suppurative tenosynovitis will result.

Treatment. Systemic care with chemotherapy must be combined with open operation. Operation must be prompt and provide adequate drainage. This drainage must not be produced by a horseshoe type of incision *or a midline incision, but only by an incision along one side of* the finger, sufficiently deep to divide all the fibrous septa that run vertically from the skin to the periosteum. The wound is packed open and wet dressings are continued for 3 days, when the packing may be removed. For this operation general anesthesia is recommended.

Infectious Tenosynovitis

Infectious tenosynovitis is best illustrated in the hand and forearm, for we find these sites most frequently involved. It is always serious and may result in complete loss of function of the involved digit, together with considerable permanent stiffening of the hand. Though the offending organisms are usually the streptococcus or staphylococcus, other organisms may affect the tendon sheaths.

Clinical Picture. From a clinical point of view the synovial sheaths

these infected hands should be started as soon as the patient comes out of the anesthetic; later results will repay him for his initial pain and discomfort if movement is forced. The appropriate type of chemotherapy is indicated.

When the dorsal synovial sheaths are infected, splitting of the sheath throughout its course apparently gives the best results, but this locality is much less frequently affected than the palmar sheaths. The danger of the fascial spaces being involved is less with the infection in this location.

Postoperative treatment. The treatment pursued in the first few days following incision and drainage is very important. It is a good plan to immerse the patient's hand and forearm in hot sterile water several times each day while the surgeon gently and passively moves and extends the fingers and wrist. This early, gentle manipulation will encourage the patient to move the involved tendon sheaths.

Penicillin or streptomycin is routinely used in all the streptococcic, staphylococcic and gonococcic infections involving tendon sheaths.

Gonococcal tenosynovitis can be established by the history of a recent urethritis and by finding the organism on smear. It is not as common a complication of gonorrhea as a transient multiple arthritis, but, when found, is best treated by local rest to the part and chemotherapy.

Syphilis involving the tendon sheaths is occasionally seen but is not a rapidly fulminating process, although it may be a manifestation of the disease in its early stage. It yields most satisfactorily to antiluetic treatment.

Dupuytren's Contracture

Dupuytren's contracture is relatively rare, occurring in 1 to 2 per cent of the population. It may occur in both the hand and the foot, giving rise to flexion of one or more fingers or toes. It is sometimes associated with epilepsy. It is also often associated with Peyronie's disease, an induration of the penis. The ring finger is most often affected and may be drawn down against the palm, interfering a great deal with laboring activities. As a rule, it is not painful, occurring most often in white males past middle life It was first described in 1832 by Dupuytren, who had the good fortune to dissect the hand of a patient whom he had treated during life for the deformity, and he was able to demonstrate the exact nature of the contracture. There is a fibroblastic proliferation of the fascia which proceeds unevenly but principally on

He has stressed that one must be familiar with the essential anatomy of the hand to appreciate and prevent dangerous complications from infections of the tendon sheath.

Following involvement of the tendon, there may be separation of the tendon, resulting in its death and destruction. Usually the patient will remember the entrance of some foreign body into the hand or a puncture of the finger. All of these penetrating wounds are particularly dangerous if located over the flexor creases of the fingers or thumb. At these points the sheath lies close to the skin and is not protected by the pad of fat found over the shaft of the phalanx. Infection may also start by direct extension of a nearby infection, and the finger will quickly assume the semiflexed attitude. Extreme tenderness will be found along the sheath throughout its entire course.

Treatment. *Operative treatment.* Immediate operation before there is necrosis of the tendon should be done to relieve the tension. If the infection lies within the tendon sheath itself, it must be quickly opened and every effort made to give adequate drainage. Incisions, therefore, must be made as outlined, placing them on the side of the finger toward the dorsum and not the flexor surface. The incision, by being placed on the side, will prevent any tendency to bowing by the underlying tendon and the resultant scar will give a minimum of functional disability. Also, the vessels and nerves will be avoided by placing the incision toward the dorsolateral surface of the finger and adequate drainage of the sheath will be provided. Care should be taken to retain the bridges of the tendon sheath opposite each joint and the skin wound, not the tendon sheath, should be loosely packed. Care should also be taken not to lift or disturb the tendon from its bed.

Following this emergency surgery, a $^{1}/_{1000}$ solution of acriflavine and glycerin or sterile paraffin oil may be used to prevent the packing from adhering to the surrounding tissues and yet permit free drainage. This dressing can be easily changed with a minimum amount of discomfort to the patient, but it need not be changed more than once a day. If this technic is employed, hot compresses and hot sandbags can be discontinued except for the first few days of the inflammatory reaction. It is well to splint the fingers but to allow motion early, so that the time of splinting can be cut as short as possible. Couch (1939) advises that the hand be laid on a pillow or carried in a sling with the palm upward, as it will fall into a much better functional position than if it is permitted to rest palm downward. This latter position may give rise to a rather useless type of "flat hand." Active movement of

these infected hands should be started as soon as the patient comes out of the anesthetic; later results will repay him for his initial pain and discomfort if movement is forced. The appropriate type of chemotherapy is indicated.

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the ulnar side of the hand. The etiology is unknown, but there is a strong hereditary factor, and trauma seems to play a part in certain cases. Some believe there is a nutritional or chronic infectious element as the basis for its development.

Clinical Picture. The first sign preceding the actual contracture of the fascia is the appearance of small hard nodules in the palm of the hand. Shortly after that the affected finger or fingers cannot be completely extended. The palmar fascia is closely attached to the skin. As the fascia contracts, the skin is drawn into folds with flexion at the interphalangeal and metacarpophalangeal joints (Fig. 237). The joints

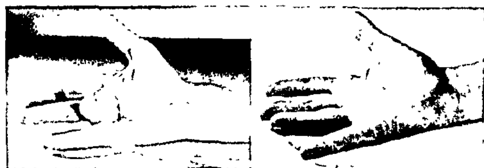


FIGURE 237. Dupuytren's contracture involving primarily the ring finger. *Left*, before treatment; *right*, following the Gill operation.

are not involved in the process. In all cases the feet should also be examined for a similar pathologic process involving the plantar fascia, for they are sometimes coexistent.

Treatment. Various nonoperative methods have been tried, but with the exception of radiation therapy in the early (nodular) stage none of them has proved effective. The method preferred by the author is complete excision of the palmar fascia involved in the abnormal process. The most successful cosmetic type of operation is that described by Gill (1919, 1938) many years ago. In this operation, he carefully and painstakingly separates the skin from the underlying fascia after making the skin incision along the flexion creases. As much of the palmar fascia is excised as appears involved. It is often necessary to make mid-lateral incisions in the involved fingers to sever the extensions of the fascia which surround the neurovascular bundle. The skin only is closed with black silk and the hand placed in a splint with the fingers slightly flexed; after the skin wound has healed the fingers are brought into gradual extension and active use begun. However, if the roentgenograms show that there is an associated arthritic process in-

volving the hand, the prognosis for a good functional result is not as satisfactory as it would be if the joints were normal. Bunnell (1956) should be consulted for other technics.

SOFT TISSUE INJURIES

Snapping Finger (Trigger Finger)

An affection of the flexor tendon sheath in which the ring finger is most often involved is called "snapping finger" or "trigger finger." It is due to a thickening of the flexor sheath, most often at the metacarpophalangeal joint; thus, active extension of the fingers forces the flexor tendon through its narrowed lumen and results in a sudden snapping of the finger into extension, accompanied by some local pain. Relief often follows injection of Hydrocortone into the area of the thickened edematous sheath. If recurrences develop simple division of the tight band of the flexor sheath causing the constriction restores the smooth gliding tendon motion. This condition is frequently associated with a low grade rheumatoid arthritis.

Mallet Finger

Mallet finger ("dropped finger" or "baseball finger") is a deformity produced by tearing the extensor tendon at or near its insertion into the distal phalanx. Frequently an avulsion fracture of the distal phalanx at the site of attachment is seen by roentgenogram. This should be splinted from 5 to 6 weeks with the first interphalangeal joint in flexion and the distal interphalangeal joint hyperextended. Occasionally open suture of the torn tendon becomes necessary, although conservative methods are usually satisfactory if splinting is initiated early and continued for a long time (Fig. 238).

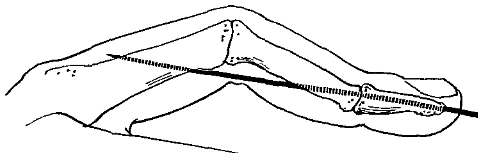


FIGURE 238. Method for treating acute baseball finger. The finger may be splinted as shown in figure without Kirschner wire fixation.

FRACTURES

It is estimated that 90 per cent of metacarpal fractures occur in men, the most common types being at the base of the first metacarpal and the neck of the fifth metacarpal. A blow or a fall on the radial side of the hand is usually the cause.

Bennett's Fracture

The fracture at the base of the first metacarpal is very unstable and results in posterolateral angulation of the bone due to the pull of the long abductor tendon. This fracture may be near the base, but when it involves the carpometacarpal joint with displacement it is called a "Bennett's fracture." (Fig. 239.)



FIGURE 239. Bennett's fracture

Treatment. The simple type of fracture may be reduced manually, using traction on the thumb and manipulation at the site of angulation by pressure on the posterior surfaces at the base of the thumb A snug-fitting plaster extending from the tip of the abducted thumb to the middle of the forearm is then applied.

Usually, however, in Bennett's fracture-dislocation, the fragments are difficult to hold in position and skeletal traction must be applied with the thumb slightly abducted while pressure is firmly made on the base, reducing the fracture and dislocation. The plaster is applied with the thumb in this position, and continuous skin or skeletal traction is exerted on the thumb for several weeks. Open operation is sometimes necessary in which a transfixion wire may be used to maintain position. Malunion causes considerable disability and pain on use of the thumb and it is sometimes necessary to fuse the first metacarpal to the greater multangular.

Metacarpal Shaft Fracture

Fractures of the other metacarpals in which the shafts are usually broken transversely, with or without marked displacement, may also



FIGURE 240. Method of strapping clenched fists over a roller bandage to hold the reduced metacarpal shaft fracture.

be produced by direct violence. Shaft fractures of the metacarpals result in little deformity as all of the metacarpals are bound firmly together and splint each other. A spiral oblique fracture of the shaft may result

n shortening. Fracture of the neck of the metacarpals usually results n the neck being displaced volarward and gives the appearance of a dropped or missing knuckle. This type of fracture occurring at the neck of the second metacarpal has been called a "boxer's fracture."

Treatment. Fractures of the metacarpals, if not compound, can usually be satisfactorily reduced manually. They are then immobilized by a dorsal splint (Fig. 240) by sharply flexing the metacarpophalangeal joint and pushing the volarward displaced head posteriorly. Immobilization can also be obtained by the insertion of Kirschner wires transversely through the shafts of the adjacent metacarpals, transfixing the broken bone. This is most successfully done under the fluoroscope.

Occasionally even open reduction becomes necessary, and the fragments are held in position by chromic catgut placed through drill holes or by a small bone graft, the hand and wrist being immobilized on a splint.

Fracture of the Phalanges

In a simple fracture of the phalanges, it is usually sufficient to reduce manually by traction and immobilize the fingers in a position of flexion. The most common deformity of the proximal phalanx is an anterior angulation due to the pull of the lumbrical muscles. The middle phalanx may angulate either anteriorly or posteriorly, depending upon whether the fracture is proximal or distal to the insertion of the sublimis tendon. Fractures of the distal phalanx are usually comminuted due to a direct blow but are not displaced. The problem at this level is that of the contused soft tissue and ecchymotic nail bed. This may require drilling of the nail to release the hematoma.

DISLOCATIONS

Dislocation of the metacarpals and phalanges, uncomplicated by fracture, are usually easy to reduce if seen early. Simple immobilization suffices; however, roentgenograms (Fig 241) should always be taken to rule out any fracture. If fracture is of the chip type, entering into the joint, or if it is more extensive, the prognosis for restoration of full function will have to be guarded If some soft tissue interposes between the surfaces, simple manipulation may not suffice and then open operation is needed.

Active splinting for hand disabilities is demonstrated in Chapter 17.



FIGURE 241. Simple posterior dislocation at first metacarpophalangeal joint.



FIGURE 242. Hands of four children of one family, each child having supernumerary fingers.

CONGENITAL DEFORMITIES

Congenital deformities at the wrist and hand may take the form of deficiencies in the normal pattern of development: accessory parts, i.e., supernumerary digits or carpal bones, webbing of the fingers and clubbing of the hand or wrist.

Supernumerary Bones

Accessory Fingers or Toes. Accessory fingers (Fig. 242) or toes are not unusual. Roentgenograms should be taken to determine the bony structure. Rarely is the function normal in the accessory thumb or finger and frequently the extra part dangles uselessly. For cosmetic reasons alone, amputation of the extra digit is usually advisable.

Accessory Bones of the Hand. A large variety of supernumerary bones may occur in the tarsal region, but accessory bones of the hand and wrist are seen much less frequently than of fingers.

Other Congenital Deformities

The rare divided scaphoid, caused by failure of radial and ulnar anlage of the scaphoid bone to fuse, is of diagnostic significance. Roentgenographically this condition resembles an ununited fracture, but most investigators believe it is of purely developmental origin. It is thought that imperfect development is a predisposing factor in traumatic fractures of the scaphoid. The unciform process of the unciform bone may develop separately, and the ulnar styloid process may not unite with the distal end of the ulna. These developmental variations are extremely uncommon and should not be confused with fractures.

Developmental fusion of one or more adjacent carpals may occur. An accessory epiphysis is occasionally seen at the proximal end of the second or the fifth metacarpal bone.

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9

The Hip and Pelvic Ring

The Hip Joint

APPLIED ANATOMY

The hip joint is the most deeply situated joint in the body and is a perfect example of the ball-and-socket type of articulation. The round, three-quarter spherical, articular head of the femur fits into the deep cup-shaped cavity of the acetabulum, giving a wide range of motion. The strong capsule and muscles protect the head from being dislocated. Over the front of the joint the capsule is thick and strong, this portion being called the iliofemoral ligament (the Y ligament of Bigelow). It is the most important ligament about the hip joint, as it checks extension and strengthens the front of the joint.

This joint has the double duty of mobility and support, and to give it security the ligaments are very strong and the socket deep, resulting in the sacrifice of some flexibility in order to obtain stability. A synovial membrane, as in all movable joints, lines the inner surface of the capsule, forming a closed sac and producing a small amount of viscid fluid, synovia, which acts as a lubricant to the joint surfaces. The ligamentum teres, a V-shaped ligamentous band about 1½ inches long running from the acetabular fossa to the head of the femur, carries an inconstant blood vessel, which when present, aids in the nutrition of the femoral head.

Muscles. The powerful muscles protecting the joint permit flexion, extension, abduction, adduction, circumduction and rotation, and any two of these movements which are not antagonistic may be combined, such as flexion and abduction. Flexion of the thigh is accomplished principally by the iliopsoas, the rectus femoris portion of the quadriceps and the sartorius muscles. Extension is accomplished mainly

by the gluteus maximus muscle; abduction, by the gluteus medius and minimus and tensor fascia femoris muscles; adduction, by the adductor longus, magnus and brevis muscles. Portions of the gluteus medius, gluteus minimus and the tensor fascia femoris muscles rotate the hip medially; the external rotators are the pyriformis, the gemelli, the obturators and the quadratus femoris muscles.

Nerve Supply. The nerves supplying the hip joint are the great sciatic, the anterior division of the obturator, which also sends a branch to the knee joint area, the accessory obturator when present, and a small branch from the anterior crural (femoral). Many patients with hip joint disease or hip joint injury complain of pain in and about the knee joint due to involvement of the obturator nerve.

Blood Supply. The blood supply of the neck and head of the femur is dependent on three groups of blood vessels. First, branches of the nutrient artery enter the shaft of the femur and supply the entire diaphyseal portion of the bone. The second group are the capsular (retinacular) arteries consisting of the posterior, superior and inferior and the anterior branches. These chiefly supply the epiphysis of the femur and arise from the medial circumflex artery. In children and infants these branches supply the ossifying center of the developing femoral head. The third type are the ligamentum teres vessels or foveolar arteries which rarely are found to enter the femoral head in children. These three groups of blood vessels anastomose when ossification is almost complete in the young adult; at that time they unite near the fovea of the femoral head and then apparently increase in size. Even in the adult Walcott (1943) could not demonstrate any vessels in the ligamentum teres in 20 per cent of his cases and felt that only in 80 per cent of adults were the vessels in the ligamentum teres visible after bone growth had been reached.

An understanding of the distinctive architecture of the femoral head and neck with its blood supply is necessary in considering the problems associated with fracture of the femoral neck (Kolodny, 1925).

EXAMINATION

At the beginning of an examination of the hip one should test the opposite (sound) limb in order to obtain a picture of the normal range of motion (Fig. 243). The examiner will then be able to evaluate more accurately the abnormal side. The student will often be tempted to try first to put the affected joint through a normal range of motion, but it

must be remembered that a small range of passive motion will often give more information and cause the patient less pain. It requires at times great skill, patience and gentleness in the examination to determine the true range of motion in a diseased or injured joint.

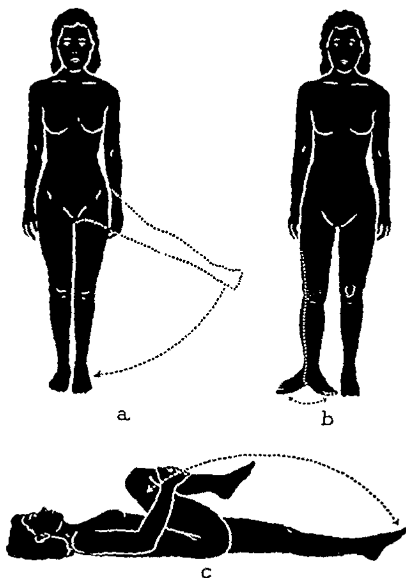


FIGURE 243. Normal range of movement of the hip in a young adult: *a*, abduction and adduction; *b*, internal and external rotation, *c*, flexion and extension.

The hip joint, being of the ball-and-socket variety, offers a wide range of movement. Examination of the patient must be in a room sufficiently large and in a good light, so that many of the gross deformities arising from limitation of motion may be easily detected by *inspection* alone. A limp manifests itself by disturbance of the normal rhythm and this is one of the earliest evidences of a diseased or injured

hip joint. One should note the type of body build and whether walking apparently causes pain.

The attitude in walking is an important aid in diagnosis. One should observe whether the limb is held flexed, extended, abducted, adducted, or inwardly or outwardly rotated, all of which may aid in diagnosing the underlying pathologic process. The observer should note also whether there is muscle atrophy, for this is an important sign of joint disease, although it is not so easily detected in this joint as in certain other more superficial joints. The cause for this atrophy is primarily one of physiologic disuse and secondarily a disturbance of nerve impulses, initiated by the underlying pathologic state. Localized swelling about the joint should be noted as well as the appearance and color of the skin.

If the patient is not ambulatory, the above examination may have to be curtailed; the patient should then be examined lying prone on a table with, if possible, the limbs parallel to one another so that their length and size may easily be compared. It should then be noted whether the lumbar spine and popliteal surfaces of the knees rest on the table simultaneously; if so, this indicates that any suspected flexion-contracture deformity is absent. In the child this is a very helpful sign, but in adults there may be a normal degree of lordosis when recumbent.

One should then begin to test by *palpation* the range of motion and the amount of pain present on careful passive movement. If the pelvis is steadied by one hand as the patient lies on the table and the thigh is gently rotated with the opposite hand, one may demonstrate the protective mechanism by which nature attempts to splint an injured or diseased part. This is evidenced by observing and feeling the muscle spasm that restricts this rotation movement. If an attempt is made to rotate the hip gently, it causes very little pain but may reveal early intra-articular disease or injury.

When the head of the femur is in its normal position, it can be felt under Poupart's ligament as the thigh is rotated with one hand and the fingers of the other are grasping the greater trochanteric region, the thumb being placed over the intersection of the femoral artery with Poupart's ligament. If the head cannot be felt in this position by the examiner's thumb, it indicates a dislocation, either acquired or congential. (Fig. 244) When the head is felt in its normal position but does not move as the thigh is rotated, it indicates a lack of bone continuity in the femur.

The integrity of the hip joint depends upon its anatomic configuration to some extent, but it also depends largely upon the strength of the muscles about the joint. The muscles act as sentries on guard, and protect, by muscle spasm, the joint motion if there is disease or injury

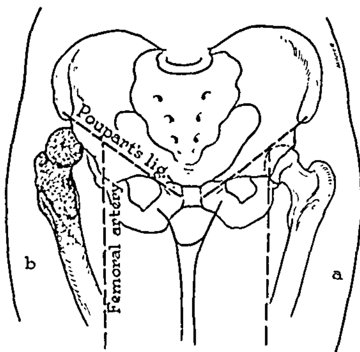


FIGURE 244. The head of the femur: *a*, normal position; *b*, congenitally dislocated, posterior in type.

present. Intra-articular or extra-articular pathologic conditions can be determined as stated by Sir Robert Jones (1920): "All movements of the joint are limited when there is an inflammatory intra-articular condition present, or some serious lesion. But if some of the joint motions are free and others limited, the obstruction is probably mechanical or due to some extra-articular cause."

After inspection and palpation have been accomplished, *measurements* of the lower extremities should be made, and the bony landmarks identified, as described in Chapter 1. Nélaton's line, Bryant's triangle and the normal range of motion should be determined. The need for roentgenographic examination must be recognized, but roentgenographic findings should primarily substantiate the history and clinical findings.

Epiphyses. It should be remembered that epiphysitis is particularly common in infancy; that Perthes' disease is usually seen between the ages of 3 and 10 years; and that slipping of the upper femoral capital epiphysis occurs not in early childhood but during the adolescent period. It is also a fact that fractures of the femoral neck rarely occur

in children; they are far more common in middle-aged or elderly patients. Osteoarthritic changes are not seen in infancy or childhood but occur in the later life. Therefore in any differential diagnosis the age of the patient is extremely useful as well as the history of the case. We must also be familiar with the appearance and time of fusion of the epiphyses (Fig. 245), for their development may at times be variable in those cases in which there are nutritional disturbances or developmental diseases.

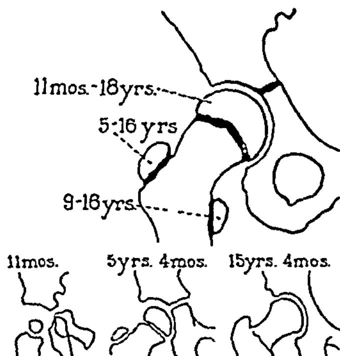


FIGURE 245. Ages at which appearance and fusion of the epiphyseal centers occur.

The roentgenogram will demonstrate that the epiphysis of the head of the femur normally appears before the sixth month and fuses around 17 or 18 years of age. Although in children only the center of this large cartilaginous cap is visible in the roentgenogram, it is obvious that disease and other conditions affecting the epiphysis must have advanced into the interior of the head before there is roentgenographic evidence of any bone change. The appearance of the joint space should always be observed; an increase or decrease in width should be noted, as well as whether the epiphyseal center appears to be higher than normal or is completely dislocated from its usual position

The greater trochanter appears in the fifth year and unites about the sixteenth year, and the lesser trochanter appears during the ninth to the sixteenth year and unites about the sixteenth. Not only the head of

the femur but also the acetabulum must be carefully studied for any abnormal changes regarding its depth or irregularity, as well as whether it is on the same level as that on the opposite normal hip. At birth the three nuclei of the innominate bone, which will later form the acetabulum, are of considerable size and are surrounded by wide tracts of cartilage. By the eighth year the rami of the pubis and ischium have united, and by the twelfth year the triradiate cartilage, which separate the three segments in the acetabulum, begins to ossify; by the fifteenth to sixteenth year the several parts of the actabulum become fused.

Special soft tissue films will sometimes bring out bone and soft tissue details that may be important in differential diagnosis.

Aspiration. The hip joint can be most safely aspirated by inserting a large bore needle laterally along the tip of the greater trochanter and neck of the femur (Fig. 246), the limb being in slight abduction. Aspiration is preceded by the injection of Novocain into skin and muscles.

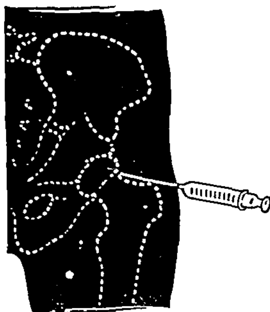


FIGURE 246. One method of aspiration at the hip joint.

DISEASES

Tuberculosis

Pathology. Undoubtedly trauma aids in development of infection by forming a point of lowered resistance where *mycobacterium tuberculosis* may gain a foothold. It is characteristic of tuberculosis of the bones and joints that there is very little new bone formation; it is mainly a destructive process, causing great rarefaction and replacement of the marrow

in children; they are far more common in middle-aged or elderly patients. Osteoarthritic changes are not seen in infancy or childhood but occur in the later life. Therefore in any differential diagnosis the age of the patient is extremely useful as well as the history of the case. We must also be familiar with the appearance and time of fusion of the epiphyses (Fig. 245), for their development may at times be variable in those cases in which there are nutritional disturbances or developmental diseases.

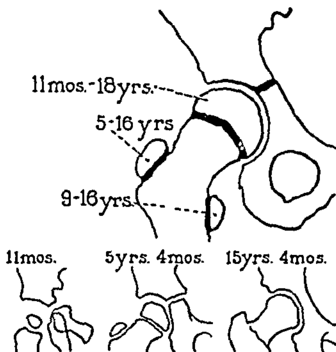


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of the knee, due to the distribution of the branches of the obturator nerve. In sudden or unguarded movements of the hip, or when the hip has been subjected to an unusual amount of stress and strain, pain may be the outstanding symptom. At night the history is quite constant, for



FIGURE 247. Tuberculosis of the hip. Note joint destruction and wandering upward of the acetabulum.

at this time the spastic muscles, which during the day have afforded an involuntary protection, relax. During sleep the diseased parts move one against the other, causing the patient to cry out sharply on movement — the so-called "night cries."

The limp is an important early sign in hip joint disease and is a constant finding. Examination of the hip will disclose a limitation of motion in all directions. Early in the disease the limb will be rotated outward, due to the increased joint fluid. The restricted motion is due partly to reflex muscle spasm, which limits the motion in all directions, which in turn is evidence of disease involving the joint cavity. Muscle atrophy shortly makes its appearance.

As the disease progresses, the bone is destroyed and the limb is instinctively drawn into a more protective attitude, i.e., flexion, adduction and inward rotation, with apparent shortening. This attitude may give rise, if left untreated, to a serious complication, that is, an upward pathologic dislocation of the head and neck of the femur. In addition to these local signs and symptoms of tuberculosis, there are usually

by fat. Early in hip joint disease there is increase in the joint fluid, and if the infection progresses a purulent exudate fills the joint so that the synovial membrane and the periarticular tissues become edematous and thickened.

It has been estimated that 80 per cent of the cases start not in the head of the femur but in the metaphyseal region of the femoral neck, 8 per cent start in the neck proper, and 17 per cent in the ilium or ischium bordering on the acetabulum. The affected foci coalesce and cause local bone destruction. The infected granulation tissue replaces the normal bone. Early in the disease a pannus (granulation tissue) spreads out from the epiphyseal region, making inroads upon the articular cartilage. The underlying subchrondral extension of the disease strips it up from the underlying bone and causes the death of the cartilage. Irregular erosion of the bone occurs and extensive excavation, collapse and wide destruction of the joint surfaces follow.

Though all portions of the hip joint soon become involved to some degree, the destructive effects of the disease are most evident at the points of contact between the head of the femur and actabulum. Here both the disease and the friction of the softened bones against one another are aggravated by continuous muscle spasm and cause early bone destruction. Abscesses which form in the hip joint may distend the capsule and cause it to rupture, resulting in extension of the abscess into the soft tissues; this extension may produce a pathologic subluxation of the remaining portion of the head of the femur. The femoral head then assumes a precarious position, that of an impending true pathologic dislocation. With involvement of the acetabulum and subsequent bone destruction there may be an upward wandering of the head, (Fig. 247), the so-called "wandering acetabulum." Abscesses in hip joint disease may "point" in Scarpa's triangle or in the neighborhood of the greater trochanter, or even perforate the bottom of the acetabulum. In rare instances they appear as pelvic abscesses. They usually follow muscle planes and the lines of least resistance.

Although tuberculous meningitis is seen most frequently as a complication of tuberculosis of the spine, it occurs also with tuberculosis of the hip joint.

Clinical Picture. Because this chronic disease is characterized by pain and limitation of motion in the hip joint, early in the disease the patient learns to bear as little weight as possible on the affected limb. Though pain is frequently found early it is usually preceded by a limp; often the patient complains of pain not in the hip but in the region

the advent of roentgenographic diagnosis. The condition is also called osteochondritis deformans juvenilis. It presents such a characteristic roentgenographic picture, however, that it should not cause confusion (see p. 406).

Multiple atrophic arthritis and *subacute pyogenic epiphysitis* may resemble tuberculosis, but these conditions are much more acute and present a different roentgenographic picture.

Tuberculosis of the spine (Pott's disease) with abscess formation along the course of the psoas muscle may cause hip flexion contractures with pain and severe disability, resulting in deformity which resembles that of hip joint disease. It can, however, be easily excluded on examination, as rotation and flexion of the hip joint in Pott's disease are both free and painless. A roentgenographic examination of the spine should be made when in doubt.

Prognosis. As in all bone and joint infections, the results depend upon the balance between the power of resistance of the patient and the virulence and degree of the infection. The exact diagnosis in the very early case is often not made until there is some joint damage sufficient to result in a definite impairment of motion. It has been stated that whenever the joint retains 45 per cent or more of its normal motion there is a better prognosis for permanent arrest of the disease than if only a few degrees of motion remain.

Treatment. This should be divided into treatment of the systemic disease by a well-balanced and nourishing diet, fresh air and sunshine, and treatment of the local lesion by a combined conservative and operative program. The limb should be put at rest and the acute pain and muscle spasm should be relieved by traction. This consists of moleskin traction which must be applied to the lower extremity in "the line of deformity" (Fig. 249). This means that if the limb is in a deformed attitude of flexion and adduction, traction must be applied in this position until the muscle spasm subsides sufficiently to permit the more ideal attitude of extension and slight abduction to be obtained. Early traction provides great relief of pain while the deformity is being gradually corrected.

Whenever roentgenograms show bone destruction surgical intervention *ultimately* will be the method of choice, although a period of several months, and sometimes longer, of conservative treatment should be employed. The roentgenograms and examination are satisfactory guides if taken at spaced intervals of time and will determine the local resistance to the infection. During the period of pain and muscle

general signs of the disease, such as debility, fever, malaise and a generally ill appearance (Fig. 248).

In an early suspected case of tuberculosis of the hip a thorough *physical examination, including roentgenographic examination,* is necessary, but even these may not be sufficient to make the diagnosis conclusive. Therefore other laboratory aids should be employed, such as aspiration and guinea pig inoculation and the Mantoux, tuberculin and patch tests; a biopsy may be necessary for conclusive proof.



FIGURE 248 Tuberculosis of the hip Note late changes of muscle atrophy, severe flexion contractures and lumbar lordosis.

Differential Diagnosis. *Contusion* caused by a trivial injury may produce the onset of symptoms and signs suggestive of joint disease, and when there is a predisposing history of injury with a tuberculous familial background one must suspect an acid-fast infection until proved otherwise. Many minor injuries produce joint irritation for only a few days or weeks and then disappear, it must be remembered that tuberculosis is an insidious and chronic affection.

Legg-Calvé-Perthes' disease (coxa plana) may closely resemble tuberculosis of the hip clinically and was often confused with it before

Acute Infectious Arthritis

Acute arthritis of the hip joint is caused by an infection of the pus-forming organisms, staphylococcus, streptococcus and gonococcus, and is seen in infancy and early childhood. It may begin in the epiphysis



FIGURE 250. Hibbs' type of hip fusion (same case as Figure 247).

but usually begins at the metaphysis, as in other forms of osteomyelitis (see Chapter 2). Because the metaphyseal area is intra-articular at the hip, the disease spreads rapidly into the joint, causing destruction of the epiphysis and giving rise to a pyarthrosis.

Clinical Picture. The onset is sudden and usually accompanied by high fever, prostration, and sometimes by nausea and vomiting. The hip joint area rapidly becomes hot, swollen and very sensitive to any attempted motion. These children are acutely sick. Aspiration of the hip joint may actually reveal pus. In the greater percentage of children the streptococcus is the causative agent, although in infancy the staphylococcus is the predominating organism present.

Treatment. In these acutely ill patients aspiration and chemotherapy, systematically and into the joint, are helpful, but usually early incision and drainage are necessary to prevent destruction of the articular

spasm, recumbency in traction or in a plaster spica should always be prescribed. As soon as the general body resistance has improved, which may take several months or longer, and if no active pulmonary lesion is present, children over 10 years of age should have an extra-articular

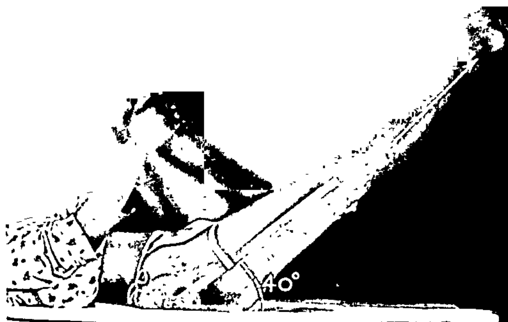


FIGURE 249. Traction applied in the line of deformity; i.e., flexion and adduction. As the muscle spasm slowly subsides the hip can be brought into extension and slight abduction. The angle of deformity is measured with a goniometer.

arthrodesis. Following this operation a period of plaster immobilization is necessary until roentgenograms demonstrate a solid bony union (Fig. 250). This requires many months of immobilization in plaster.

It may be that the antibiotics will revise our thinking, but at present in a proved case of joint tuberculosis, operative fusion is the preferred method of treatment. It must be stressed, however, that the fixation operation is not indicated before the natural resources of the body have been tested over a period of at least a few months. During this time streptomycin or Marsilid should be employed, especially in those cases with a draining sinus. In those cases with active pulmonary tuberculosis, which fortunately constitute a small percentage of the total number, the prognosis is poor for successful fusion of the hip.

Under 10 years of age approximately 25 per cent of the various infections of the hip joint are nontuberculous, and approximately 75 per cent tuberculous, whereas the reverse is true in adult life.

instances but a fusion in any neuropathic joint is not easy to obtain, especially in the hip joint (Fig. 251).



FIGURE 251. Charcot hip with nonunion following a fracture.

Osteoarthritis (Malum Coxae Senilis)

Malum coxae senilis is an osteoarthritis of the hip joint. It is far more common in males than in females; it is usually seen in adult life or old age, and though it is considered a type of chronic arthritis of the hip joint, it is not of infectious origin. This disease may also develop in persons with joint surfaces that are not mechanically perfect. The soil may be prepared in childhood by changes in the epiphyses that follow Perthes' disease, congenital dislocation of the hip or a slipped upper femoral epiphysis. It also develops in elderly patients without any known etiologic factor other than the wear and tear of hard work or in those patients with an individual diathesis.

Pathology. The disease is characterized by destruction of the cartilage of the head of the femur and acetabulum at the points of greatest pressure. Erosion of the underlying bone with the formation of masses of bone about the margin of the acetabulum and femoral head occurs. It appears to be the result of a chronic process in which the joint surfaces have been rather flattened out toward the periphery following the pressure forces of stress and strain, giving rise to a proliferation of bone (osteophytes) about the head of the femur and acetabulum in the form of a collar. During this process, the acetabulum and femoral

cartilage of the hip joint. Delayed treatment offers opportunity for permanent impairment of function.

The hip is usually drained from a posterior incision, splitting the gluteal muscles and inserting a small rubber wick down to the synovial membrane, but not into the joint. The history and clinical picture will decide whether surgery is needed immediately; undoubtedly a mild infection of the hip joint will terminate with partial or complete recovery without surgery. The use of aureomycin, penicillin or streptomycin is stressed. Occasionally these drugs alone may suffice to combat the infection successfully.

If in the acutely infected hip diagnostic aspiration is negative for any organism, traction should be applied in the line of deformity and chemotherapy instituted until all clinical signs of infection have disappeared. The hip should later be protected by a brace against weight bearing for months or until such time as the roentgenographic evidence indicates healing has occurred.

Complications. In cases of epiphysitis with rapid destruction of the head of the femur, there is a definite tendency toward *pathologic dislocation* upward and backward of the remaining portion of the shaft and neck, so that if flexion and adduction seem imminent, traction must be continued so that the hip will heal in the best attitude for weight bearing, that is, extension and slight abduction. In those cases of pathologic dislocation in which the infection has completely subsided but the deformity is severe, and provided the infection has been quiescent for at least 6 months, an open operation and surgical fusion of the hip may be desirable. In the younger age group a nonweight-bearing type of brace should be worn; rarely is it desirable to attempt fusion in a nontuberculous hip joint before 8 years of age.

Charcot's Joint

Charcot's joint is not common, but may be seen as a destructive neuropathic arthritis — the so-called Charcot's disease. The various joints are involved in the following order of frequency: knee, hip, foot, shoulder and spine. Usually the painlessness, the extensive destructive arthritis without bone atrophy as noted in the roentgenograms and the laxity of the joint ligaments make one suspect Charcot's disease. Blood and spinal fluid tests should be made to confirm the diagnosis

Attempts must be made to treat the general infection and to give local support, such as a brace to lessen further deformity and give stability to the joint. Fusion of the joint has been done in a number of

space with some increased density at the point of greatest pressure, which is usually on the superior surface of the femoral head in its contact with the acetabulum. This discomfort, with limitation of motion, will be followed by actual pain on each attempt to perform the already restricted motions of the hip. Soon definite limitations of motion in the attitudes of abduction, adduction, and especially rotation becomes more marked. When the hip is flexed, it will be noted that the limb rotates outward rather than maintaining its neutral position, and that internal rotation is restricted by a bony block.

In the late stage of this disease the roentgenograms show distinct osteoarthritic changes about the joint. The patient presents a stiff, painful joint that is completely disabling. Weight bearing, which is performed with the affected limb in the flexed and adducted attitude, is awkwardly done and the pain severe.

Differential Diagnosis. Without roentgenograms, tuberculosis of the subacute type, subacute pyogenic infection, or occasionally an atrophic type of arthritis may be confused with this monarticular hip disability, but in each of these conditions the roentgenographic picture usually presents characteristic findings and should not give rise to any confusion in diagnosis.

Treatment. As the condition produces a malalignment of the joint surfaces by joint attrition and proliferation of bone, any medical treatment in the hope of checking the progress of the disease is usually not successful. One should, however, emphasize a diet low in carbohydrates and proteins, with general attention to the removal of any foci of infection. Nonweight-bearing exercises of the hip combined with mild sedatives for the relief of pain are helpful.

Once structural joint changes are established they are most difficult to correct. These cases will surely give symptoms of joint irritation — complaints of pain, stiffness and limitation of motion. The clinical examination will give a very good idea as to the extent of the degenerative process; but it is from a careful study of the roentgenograms that we must frequently make our decision regarding employment of conservative care or the use of various types of surgical procedures that are available. Roentgenographic changes may vary from a slight narrowing of the joint space to gross and bony changes in the head and acetabulum, and it is in the early or preventive stage that conservative treatment is the method of choice. However, some type of conservative therapy, be it good or bad, is almost always found to have been applied in the early phases of every case of degenerative hip disease.

head enlarge; the head of the femur becomes irregular, and in some instances subluxation takes place, all producing an incongruity of the joint surfaces as though putty had become calcified in its mashed down state. Some definite injury may hasten the onset of symptoms.

Clinical Picture. This affection is seen frequently, especially in the hardworking, stout type of laborer, and the symptoms are so insidious that they may be overlooked until there is gross roentgenographic evidence of joint disability. As the disease progresses, the clinical picture is of increasing pain and restricted motion. The progress of the disease is usually slow, though in certain cases it may be quite rapid and may be mistaken for tuberculosis of the hip. Any underlying active infection in the body may aggravate the symptoms.



FIGURE 252. Malum coxae senilis (osteoarthritis). Note the lack of bony ankylosis, the narrowed joint space and the sclerotic and deformed femoral head and acetabulum.

Among the earliest changes noted by the patient is some inability to perform a particular movement, such as crossing the legs or tying the shoelaces, or sudden neuralgic pain in the limb. At first the symptoms may appear in the morning and wear off during the day. In the early stage the roentgenogram (Fig. 252) may show only a narrowing of the joint

of the coal-tar derivatives and small doses of codeine have been tried, but on the whole the use of drugs has been disappointing. This is not surprising as the condition is primarily a degenerative process of the osseous and soft tissues of the joint.

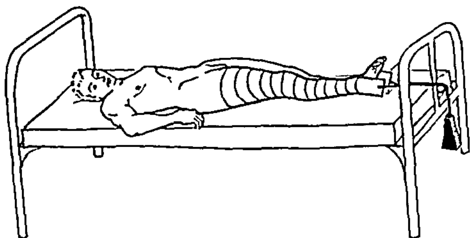


FIGURE 253. Buck's extension. See also Fig. 477.

Butazolidin is at times helpful but it is safer to have the patient in the hospital during administration of this drug.

Hydrocortone, 1 to 2 cc. injected intra-articularly, does in many instances lessen the pain but it is far from a cure-all. Apparently repeated injections at weekly intervals give no systemic ill effects and some patents respond very well, with a feeling of well-being and lessened local pain.

In private practice the average busy adult patient is most anxious to try a period of conservative treatment before resorting to surgery and in many of the cases considerable relief is afforded by one or all of these conservative measures. Proper evaluation of the patient as a whole must go hand in hand with any conservative treatment of the local arthritic lesion.

Operative treatment. In the early stage of the disease conservative measures of restricted weight bearing, traction to the limb, baking, massage, and the use of crutches should be resorted to with the expectation of a fair degree of success, but when the disease is more extensive and there is roentgenographic evidence of severe arthritic change and joint destruction, surgical procedures should be considered.

This must presuppose that in most instances at some time during the course of previous treatment the patient has received the accepted conservative treatment and that the surgeon considers further conservative care to be a waste of time for the patient. Of course, conservative

Nonoperative treatment. Conservative care may be the only suitable treatment advisable in certain cases that surgery would improve but in which the risk of operation might be too great. After degenerative arthritis has developed the problem largely becomes a mechanical one. The irregular joint surfaces and bony proliferations about the articular margins of the joint should direct our attention to limiting the stress and strain to which the joint is placed during weight bearing. Many times the process can be delayed in its development if unnecessary body weight or weight bearing can be eliminated. In laboring occupations this is often impossible but in other individuals a great many alterations can be suggested in the daily routine that will result in saving the joint from unnecessary trauma. However, the hip joint is one joint that does not particularly well lend itself to a brace to accomplish this. The older patient finds it difficult to becomes accustomed to an ischial type of brace or any other type of brace that can at best only partially relieve the joint of its weight bearing.

Gentle stretching of the hip under anesthesia and placing the limb in some abduction and extension for a period of 4 to 6 weeks may increase the range of motion and give temporary relief. A short spica hip brace or a celluloid casing may be worn and sometimes is of benefit in preserving the range of motion and preventing the return of pain. If one hip is involved the use of crutches and elevating the shoe on the sound side is one of the simplest methods to still keep the patient ambulatory and yet lessen trauma to the hip.

The second way of conservatively treating these patients is to use some modality to increase circulation through the degenerative and scar tissues. Heat applied to the surface of the skin, heat applied to the interior of the joint by diathermy, and either or both followed by gentle massage are methods of physical therapy that have been found useful If it is possible for the patient to live in a dry, warm climate or to utilize natural or artificial sunlight by sun bathing, some improvement seems to accrue.

The third point to keep in mind is to watch the attitude of the hip and guard against flexion and adduction deformities. Any joint irritation has a tendency to pull it into the deformed attitude. Sometimes a Buck's extension (Fig. 253), using 5 to 10 pounds, applied only at night in the early phases of the disease, may allow a hip that shows definite arthritic changes to be preserved in its maximum position for activity.

Salicylates are of some value in combating pain; the judicious use

improvement of these milder types of cases must be due to rest from weight bearing and to physical therapy.

(3) The value of the McMurray osteotomy, which is a simple procedure, has not been recognized sufficiently. The author is somewhat at a loss to explain the reason for its great benefit, but has been impressed with the fact that both in the bilateral and in the unilateral case of chronic arthritis with joint destruction, its use can make patients more comfortable and increase their power of ambulation. It is probably due to a combination of factors which are inherent in the McMurray osteotomy operation. In the first place, the stresses and strains of weight bearing on a particular area of the head and acetabulum are shifted, so that a new area of femoral articulation is mainly utilized. This must be beneficial for it relieves this area from receiving the body weight when each step is taken. The operation also stimulates the circulation in the vicinity of the hip joint and therefore produces improved vascularity. It may be that this is a very primary reason for its value, for by increasing the local vascularity it must stimulate joint repair (Fig. 254). In addition, the period of rest that the operation entails is also a beneficial factor.

The teachings of McMurray and McEarland and others in not employing internal fixation to hold the bone fragments have frequently been followed; it is felt that the compression forces produced at the osteotomy site by the surrounding muscles allow closer compression. The author has seen instances in which metal fixation has held the fragments apart and led to nonunion. This has not happened often but when it does, it gives rise to unsatisfactory results. Thus, the author applies a plaster spica with the limb in the desired abduction attitude and waits from 6 to 12 weeks before removing it, taking care that the head and the shaft of the femur are in as near a straight line as possible. The thrust then produces a valgus position, thereby hastening bony union in one unified mass at the operative site of the greater trochanter, head and shaft. This has been a most satisfactory operation in many cases of chronic arthritis.

(4) The Whitman reconstruction operation is another surgical procedure advocated in selective cases. This is an old operation which consists of removing the head and reshaping the neck of the femur so that the latter fits into the acetabulum well, after which transplantation of the greater trochanter with its attached muscles downward onto the shaft of the femur in the routine manner is done. By reshaping the neck with its underlying necrotic bone, the operation, of course, must

care must sometimes be persisted in because the patient's general condition will not permit surgery. As a matter of fact, most of those cases needing surgery have usually exhausted the value of conservative care and when first seen by the orthopaedic surgeon are in such a marked state of pathologic change that one can expect no relief from the increasing disability except by means of surgery.

Preferably, the patient should have a unilateral disability in order for the surgeon to promise a good deal of benefit through an operation. The surgeon must be cautious in promising too much to the patient with bilateral advanced arthritic changes accompanied by deformity. The benefit must be predicated on the basis of occupation, age, and degree of disability from which the patient is suffering. A discussion of some of the many and various operative procedures used in the treatment of the chronic arthritic hip follows:

(1) One of the mildest forms of surgery for ameliorating the pain and disability of the chronic arthritic hip is that of tenotomy and myotomy. In most of the chronic arthritic hips, the flexion and adduction contracture slowly develops over the years, and in these patients a subcutaneous tenotomy of the adductor muscles and stretching of the soft tissues on the front of the joint is sometimes quite helpful. With the limb then placed in a plaster spica for 6 to 8 weeks in a position of full extension and slight abduction, many painful hips can be so improved that more radical surgery can be delayed for many months. Of course, many of the conservative measures are useful adjuncts, such as baking, massage, diathermy, intra-articular Hydrocortone, and proper external protective apparatus, such as a well-fitting brace or crutches to keep the limb as much as possible in slight abduction and full extension.

(2) A few years ago there was a good deal of interest and enthusiasm for the neurectomy, either using the intrapelvic approach and sectioning both divisions of the obturator nerve, or making individual exposures in the abductor region on both sides and identifying, isolating, and sectioning or crushing the branches of the obturator nerve to the adductor muscles. Along with the obturator neurectomy, the branches of the sciatic nerve supplying the short external rotators were many times divided. In the author's experience, neurectomies have been of value only in the very mild type of arthritis, and not in those cases showing incongruity of joint surfaces, mushrooming of the femoral head or extensive involvement of both the head and acetabulum. Neurectomy operations have been very disappointing. Some of the credit for

of the hip joint in the attitude of abduction and complete extension are encouraged. This post-plaster 3-week period of passive exercises is an essential feature to the end result obtained. In unilateral cases, a satisfactory result has been almost uniformly produced; and in bilateral cases, lessening of the pain has been beneficial to the patients. There is, following the Whitman operation, a restriction of motion which is a real drawback to its use. The increase of stability and the lessening of pain, however, more than offset this one disadvantage.

(5) Another surgical procedure, used only for the unilateral chronic arthritic hip, of course, is the fusion operation (Fig. 255). This gives rise

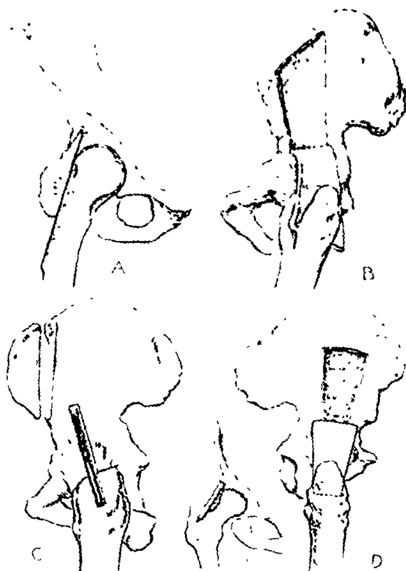


FIGURE 255. Intra-articular and extra-articular (para-articular) arthrodesis of hip. *A*, Hibbs; *B*, John C Wilson; *C*, Ghormley; *D*, Henderson.

of necessity result in limited motion. The important leverage action of the abductor muscles can be retained and in fact improved by transplanting them downward and channels can be opened for in-



FIGURE 254. Chronic arthritis of hip. *Top*, before treatment; *bottom*, after McMurray osteotomy.

creased vascularity in the hip region. In those cases which disclose a fair gross appearance to the articular cartilage of the acetabulum, there has been a distinct lessening of the pain on weight bearing.

In the Whitman operation, a plaster immobilization spica is retained for 4 weeks, followed by its removal and a 3 or 4 week period in bed. During the latter period daily stretching and passive motion

The other surgical methods utilizing some form of foreign material are the acrylic Judet or some similar type of stem prosthesis and the intramedullary type of prosthesis, both of which have been used a great deal in recent years. However, it is still too early to fully evaluate their efficiency. At present, vitallium and stainless steel are widely used, though titanium has its advocates. In the author's experience the stem prosthesis for the chronic arthritic hip has not proved particularly satisfactory. In the middle-age group of patients, the author has seen and had instances in which the stem prosthesis has eroded into the trochanteric portion of the femur, so that the hip becomes rather unstable and the patient apprehensive of his stability. On the other hand, this is not a uniform complication. However, the intramedullary type of prosthesis has given more satisfaction than the stem type.

In the elderly patient with pain and stiffness, so that there is a lack of sufficient mobility to sit and to use chairs comfortably, both types of prosthesis offer a definite lessening of pain and an increase of mobility. The fact should be stressed, however, that although occassionally a patient seems to be satisfied, a warning should be given against the danger of using either prosthesis in the active, vigorous, middle-aged patient, particularly in the laboring type of individual. In the very elderly and sedentary patient, the author has personally preferred the intramedullary to the stem type of prosthesis. It seems to give more stability and the patient seems to be more satisfied. Again, one rarely gets a long-time follow-up study of these elderly patients for death frequently intervenes. The ability to flex the hip is always valued by the patient and if weight bearing must be employed during the major portion of the waking hours, the stem prosthesis has in general proved less satisfactory than the intramedullary type. There are so many grades and degrees of chronic arthritis that one type of operation should not be expected to solve the problem of the various kinds of arthritis. We are dealing with a pathologic process both of a degenerative and a proliferative type. The problem of the disease itself as well as the mechanical irritation that the disease necessarily produces causes pain, and our main object should be one of lessening pain.

Coxa Vara

The term "coxa vara" indicates a lessening of the normal angle of the head and neck with the shaft of the femur. It may be caused in a variety of ways. In the adult the normal angle is approximately 128 degrees (Fig. 256). Coxa vara may be moderate or severe. The term

to an almost painless hip, but it must be remembered that in cases with severe lumbar arthritis or sacroiliac arthritis, one may simply transfer the seat of the painful area. It is wise to preoperatively study the lumbar vertebra and sacroiliac joints for early arthritic changes. This may deter one from doing the fusion. However, in the younger patient with no arthritic changes or very mild ones in the areas mentioned, the operation proves most successful. The optimum position for the weight-bearing, active, laboring individual is different from that needed by the patient with a needed sedentary, desk-like kind of occupation. Another factor against utilizing this operation in the elderly patient is that it requires a long period of immobilization to produce fusion.

The author has preferred the Hibbs type of fusion, using the greater trochanter or a portion of the bone graft removed from the greater trochanteric area and placing it deep within the denuded cartilaginous area of the acetabulum. This fixes the limb in the proper position of 12 to 15 degrees abduction and slight flexion. In a few instances, a long Smith-Petersen nail has been added after the articular cartilage excision and found to be fairly satisfactory. An osteotomy at the level of the lesser trochanter seems to lessen the period of immobilization.

(6) Another type of reconstruction operation is mentioned simply to condemn its use for the arthritic hip. This involves the insertion of the greater trochanter into the acetabulum and the transfer downward of the abductor muscles on the femoral shaft, as the author described many years ago for the ununited hip. This operation was not devised for the arthritic hip and is not recommended for its treatment. It is felt that any condition that produces a degeneration of the shiny, glistening cartilage covering the acetabulum is a definite contraindication for the trochanteric reconstruction operation.

(7) Another surgical procedure valuable to the orthopaedic surgeon is that of utilizing some form of foreign material which may either be one of the various types of cups, such as the Smith-Petersen cup, or the stem type of prosthesis, such as the Judet, or the intramedullary type of prosthesis, such as the Fred Thompson or Moore type. Within the past few years, the intramedullary type has been used successfully a number of times.

Smith-Petersen's original monumental contribution (Smith-Petersen, 1936) to the subject of arthroplasty on the hip is well recognized and the cup arthroplasty is a favorite type of operation in this country and abroad. It is of value in selective cases of chronic arthritis due to degenerative changes.

or bowlegs. Usually the patient complains of stiffness or weakness and pain after overexertion, and when activity is forced, muscle spasm and severe disability may result.

Differential Diagnosis. As this condition is produced in a number of ways, the cause in the individual case should be sought and treated accordingly. In children, without the use of roentgenograms, it is clinically mistaken for bilateral or unilateral congenital dislocation of the hip, and in young infants it may be difficult to differentiate by manual manipulation alone. However, in coxa vara roentgenograms show the head of the femur in its normal position. Examination reveals that telescoping is impossible, although on casual observation the lordosis, shortening, and limitation of abduction might easily suggest a congenitally dislocated hip.

Coxa vara has also been mistaken for tuberculosis of the hip. However, hip joint movements are limited by muscle spasm and pain in the acid-fast infection. The roentgenographic aspects and other laboratory data are so different that this error should not be made.

If the coxa vara is essentially on a rachitic basis, other generalized deformities accompanying rickets will be found.

If the coxa vara is due to epiphyseal slipping or fracture, the roentgenographic examination should easily make the differentiation clear.

Treatment. If the condition is on a rachitic basis, protection against weight bearing in the early stages of the disease or keeping the limbs in an abducted position in a splint or cast may be all that is necessary in young children to slowly restore the normal angle at the hips. The hips should also be moved daily and gently stretched into further abduction in order to avoid stiffness in the hip joint. Baking and massage are helpful in improving the tone of the muscles while this rachitic type of coxa vara is being corrected gradually in a bivalved spica.

To treat the deformity in the later or healed stage of rickets and in other causative conditions, an open operation is indicated. A wedge-shaped osteotomy with the apex at the level of the lesser trochanter will restore the normal angle of the femoral neck. The limb is then placed in plaster in a position of wide abduction until bony union has occurred; only then may weight bearing be gradually permitted. This usually requires about 8 to 10 weeks of plaster immobilization. With the osteotomy of the bone, a subcutaneous tenotomy of the abductor muscles may be necessary. This is due to the accommodative shortening they have undergone, and is noted in cases of long-standing coxa vara.

When the deformity is due to epiphyseal slipping, a restoration of

does not indicate the pathologic condition that may be the cause, as it may be found in a number of different conditions. It is a mechanical abnormality and is not in any way a diagnosis, but through use has been accepted as a descriptive term such as genu valgum (knock-knees) or pes planus (flatfeet).

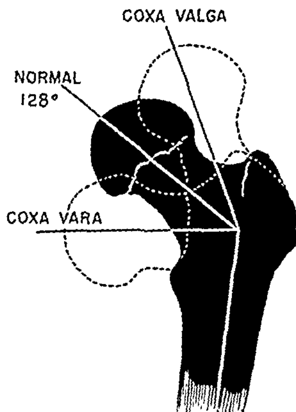


FIGURE 256. Coxa valga and coxa vara of hip.

Occurrence. It may be found in congenital abnormalities such as cervical coxa vara (see Fig. 299), or it may be acquired through injury such as seen in a malunited fracture of the neck of the femur, or in nutritional deficiency diseases such as rickets. Unilateral coxa vara is principally of traumatic origin whereas rickets is an illustration of the bilateral type. In rickets the softening in the bone causes a change in the relationship of the neck and shaft of the femur, lessening the normal angle. The anatomic deformity may be primarily in the neck region or in the head, or it may involve both the head and neck of the femur.

Clinical Picture. If unilateral coxa vara is present, a limp will be noticeable; if bilateral, a distinct waddling gait. The awkwardness in walking, combined with the shortening, limitation of motion and deformity that is produced, is more disabling than either knock-knees

by a disturbance of circulation following a mild type of infectious arthritis. In these cases the onset, pain and limp, with limitation in motion, are gradual. In the acute stage, tenderness, muscle spasm and pain on motion develop and as long as muscle spasm persists, treatment should consist of rest in bed with traction.

Coxa Plana (Osteochondritis Deformans Juvenilis; Legg-Perthes' Disease; Pseudocoxalgia; Legg-Calvé-Perthes' Disease)

The above names are all used to indicate a condition occurring as a rule in children between the ages of 3 and 10 years. It is more common in boys than girls and is characterized by a flattening of the head of the femur and a thickening of the femoral neck. The affection was first described by Legg (1910) of Boston; by Waldenstrom (1938) in Sweden; by Calvé (1921) in France and Perthes (1910) in Germany. It may be unilateral or bilateral. Perthes employed the very descriptive name "osteochondritis deformans juvenilis." "Coxa plana" was suggested by Jansen (1923).

Pathology. Osteochondritis deformans juvenilis, as the name indicates, is a *deforming avascular necrosis of the upper femoral epiphysis* in the young. No definite evidence has been presented proving that it is of infectious origin or due to endocrine dysfunction, although both theories have their advocates. The subchondral necrosis of the femoral head, produced by arterial obstruction of undetermined origin, is accompanied by flattening of the osseous center of the head and thickening of the neck. On opening the joint the articular cartilage may appear smooth or even have a wrinkled appearance similar to the skin of a shriveled apple. Although the articular cartilage of the acetabulum is usually smooth and normal; the synovial membrane of the capsule is thickened, and blood vessels in the ligamentum teres or capsular arteries may show obliterative changes during the acute stage. Legg recognized two types, the *mushroom* type in which the head is flattened and expanded and the *cup type* in which the bony center becomes segmented and the epiphysis tends to migrate toward the trochanteric region He believed the cup type offered the better prognosis for ultimate full function.

Clinical Picture. Usually children complain of discomfort in the hip, thigh or knee after excessive exercise Pain is not always a prominent feature, but the child in the early stages of the condition has a definite limp and presents slight muscle atrophy with limitation in the extremes of motion, particularly abduction and rotation. The hip may at times

the relationship of the femoral head and neck is desirable, as described under this condition (p. 409).

Coxa Valga

This is a condition in which there is an increased angle of the neck of the femur with the shaft, in contrast to coxa vara, and which tends to produce increase in the length of the extremity. Its exact etiology is not known; it may be of congenital origin, although it is sometimes found associated with infantile paralysis (Fig. 257). It probably de-



FIGURE 257 Coxa valga in infantile paralysis. Note also the underdevelopment of the right innominate bone and femur on the side of the paralysis.

velops as a result of the body being relieved of the molding forces of normal stress and strain. This condition is not common and in most cases requires no treatment, but if the coxa valga is severe, an osteotomy to decrease the angle of the neck of the femur may be done. Sometimes, if there are no contraindications to weight bearing, the deformity may slowly and gradually correct itself after the patient becomes ambulatory.

Coxa Magna

An enlargement of the femoral head and neck in the growing period has been described by Ferguson (1939), who believes this is caused

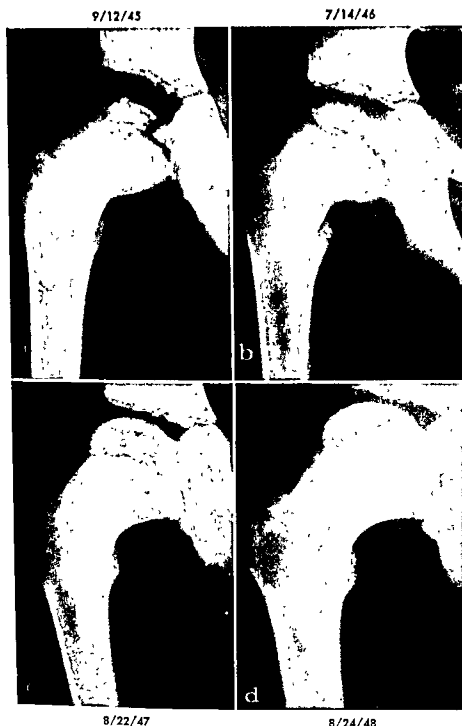


FIGURE 258. Legg-Perthes' disease. Stages of degeneration, fragmentation and regeneration. Observe the average time of healing or revascularization of the area.

consist of prolonged, uninterrupted and continuous rest from weight bearing. The longer one can prolong the period of nonweight bearing in these children, the better the functional end result. In the usual case, allowing the child to stay in bed without the use of plaster or brace offers the best opportunity for lessening muscle atrophy and limita-

present the various signs and symptoms of hip joint disease, especially muscle spasm, closely simulating tuberculosis.

Roentgenographic Findings. Anteroposterior and lateral roentgenograms should always be taken. The lateral view shows the early deformity more definitely. In the early case one constant change is an increase in the distance between the epiphysis and the bottom of the acetabulum. The epiphysis is flattened and often the epiphysal center segmented, whereas the neck appears broader and shorter than normal. Occasionally the acetabulum shows roentgenographic evidence of fragmentation.

The following four stages may appear roentgenographically: (1) *Degeneration*, the epiphysis appears roughened and its flattened surface shows evidence of a vascular necrosis. (2) Later, *fragmentation* of the epiphysis will become evident. A thickening or broadening of the neck can be noted, and even a coxa vara deformity may develop. This process of fragmentation is similar to avascular necrotic process in other portions of the body. (3) These necrotic, sharply defined areas are gradually absorbed during the *stage of repair*, and (4) the normal structure of the flattened epiphysis may be gradually restored in the *regenerative or healed stage* (Fig. 258).

Differential Diagnosis. In the acute stage, the clinical picture may closely simulate early tuberculosis of the hip. Other conditions to be considered are various types of coxa vara and slipping of the upper femoral epiphysis. This latter condition, however, need not be confused clinically with Legg-Perthes' disease; slipping of the upper femoral epiphysis occurs very rarely before the age of 10, whereas Legg-Perthes' disease does not start as late as the adolescent age period (12 to 17 years of age). The roentgenogram alone, however, should clarify confusion regarding the above conditions.

Prognosis. Coxa plana is a self-limiting disease but the healing process may be hastened and the functional end result greatly improved by proper treatment. The usual end result is a certain amount of flattening of the upper femoral epiphysis in the healed cases, but the hip often presents an excellent range of motion in childhood. However, these surface incongruities of the joint persist and the hip is more easily predisposed to arthritic changes later in life. Many patients with Perthes' disease which has healed may, therefore, develop a slight limp and some restriction of hip motion years after, and by roentgenographic examination show arthritic changes.

Treatment. In the acute stage, recumbency with traction in the line of deformity and in the abducted position is indicated; this should

the local circulation by drilling or curetting into the epiphysis via the neck or greater trochanteric region. To date the data are not conclusive that this form of treatment produces a shortening of the healing time sufficient to overbalance the dangers involved with open operation.

In healed adult patients with marked disability and bony deformity, Whitman (1929) has recommended his reconstruction operation. A subtrochanteric osteotomy has also been used to improve the mechanics of weight bearing in older patients with severe joint deformity, and in those cases with a shallow socket or a very enlarged head Gill (1941) recommends a shelf operation.

Osteochondritis Ischiopubica

Legg-Perthes' disease is primarily an osteochondritis of the femoral head, but there is a rare osteochondritis primarily of the acetabulum which has been given the name osteochondritis ischiopubica. This change in size and shape of the acetabulum is due to disturbance in the local circulation similar to avascular necrosis. The symptoms are limitation of motion, limp and some pain, and the roentgenographic picture shows the pathologic process to be primarily in the acetabulum. The socket is shallow and, if rest in bed and traction alone are not sufficient, stability of the acetabulum may be obtained by a shelf operation. The great majority of these patients, however, do not require operation.

Osteochondritis Dissecans

Osteochondritis dissecans is characterized by a partial or complete detachment of a portion of the articular surface of the head of the femur. This osteocartilaginous body may lie within its deep crater or become dislodged and wander loose in the joint. The most common site is in the knee joint but the condition occurs in other joints, occasionally in the hip, elbow or shoulder. When it gives rise to symptoms of pain or causes locking of the joint its removal is indicated.

Epiphyseal Coxa Vara (Slipping of the Upper [Capital] Femoral Epiphysis)

This is really a fracture of the neck of the femur at the epiphyseal line. It is most often observed in children between 10 and 15 years of age, i.e., the adolescent age of rapid growth. There are two distinct types: the *traumatic* and the *nontraumatic*.

Clinical Picture. The *traumatic* type is found in the tall, thin child

tion of motion. The area of avascular necrosis will be replaced by normal bone structure in approximately 2½ to 3 years, so that if it is possible to enforce bed rest for that length of time the end results will be much better. Another method of permitting activity without weight bearing is to allow the child to walk with crutches, keeping the knee on the affected side slightly flexed by a leather cuff laced about the ankle and suspended by a strap over the shoulder (Fig. 259). A



FIGURE 259. A method for ambulatory patients of keeping the affected hip from bearing weight

further method is to have the patient fitted with a Thomas ring splint with an elevation of the shoe on the opposite side, although by this method one achieves only partial freedom from weight bearing on the affected hip when walking

However, in cases that have received recumbent care for several years, such as can be offered in convalescent homes, the restoration of normal shape to the femoral epiphysis has been most striking.

Operative treatment. In an attempt to hasten the reparative process at the site of avascular necrosis, efforts have been made to improve

or knee on exertion. Examination shows that internal rotation is completely restricted by bony block and that abduction is much restricted, the other motions being normal or increased in range. If the condition is unilateral some degree of shortening can often be demonstrated.

Differential Diagnosis. Differential diagnosis should be made clinically between epiphyseal coxa vara, early tuberculosis of the hip, some acute infectious process or fracture of the neck of the femur. The history, body build and clinical picture will usually suffice to make the diagnosis evident. If in doubt, roentgenograms should definitely establish the diagnosis.

Roentgenographic Findings. The earliest roentgenographic evidence is demonstrated by noting that the normal upward curve of the superior border of the epiphysis on the anteroposterior view is absent, so that the upper surface of the neck is continuous as a straight line. An anteroposterior and a lateral roentgenogram of the hip should always be



FIGURE 261. Slipping of the upper femoral epiphyses. The slipping downward and backward is slight on the right, and severe on the left.

taken. In all cases a definite roentgenographic change is noted in the metaphyseal area. In the early case, this area appears to be widened and to have undergone some softening, rendering the slipping possible. The epiphysis is displaced downward and backward in relation to the neck (Fig. 261). Some vascular disturbance at the epiphyseal line presumably precedes the actual slipping.

Pathology. Due to the causes noted, the epiphysis begins its down-

who has a history of rapid physical growth immediately preceding the displacement of the epiphysis.

The *nontraumatic* type is found in the fat child with definitely underdeveloped sexual characteristics (Fig. 260), the so-called *Fröhlich's syndrome*, showing evidence of some disturbance of the endocrine system. Some authors feel that hypofunction of the pituitary gland is the

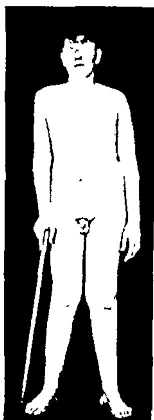


FIGURE 260 Bilateral slipping of the upper femoral epiphyses. Note body build suggestive of endocrine adenopathy

underlying cause of the softening at the metaphyseal area which renders these heavy children more susceptible to epiphyseal displacement.

In both varieties some apparently trivial injury may appear to cause the onset of the disability. The probability of some disturbance of the pituitary hormones cannot be completely excluded in many cases.

These patients, with or without known injury, begin to limp and complain of stiffness and discomfort at the hip or knee. This may be of a rather mild degree and the patient may not present himself for treatment until the disability is well advanced. At that time it will be noted that the patient walks with a severe limp and keeps the affected limb noticeably rotated outward, complaining of some pain in the hip

apply plaster, but the limb should be supported by balanced traction in bed, and early motion should be started. A prolonged period of freedom from weight bearing is then necessary either by the method shown in Figure 257, or by an accurately fitting Thomas ring splint on the affected side and elevation of the shoe on the opposite side. This type of brace permits the majority of the weight to be borne on the ischial tuberosity rather than on the head of the femur. Direct weight bearing should not be permitted for 9 to 12 months after the open reduction.

It is to be remembered that whether these cases are treated by closed manipulation or open operation, the percentage of excellent functional results depends on accurate reduction, firm fixation and delayed weight bearing.

Severe limitation of joint motion with or without avascular necrosis of the head fragment is the main complication to be feared, especially in the Negro race.

SOFT TISSUE INJURIES

Bursitis

More than 18 bursae have been described about the hip. When the bursitis is acute, movement at the hip joint is restricted, painful, sensitive to pressure, and often gives rise to a train of confusing symptoms (Fig. 262). Bursitis may be infectious or traumatic in origin. The most common are discussed briefly.

Subgluteal (Subcutaneous Trochanteric) Bursitis. It is important to differentiate this from pyogenic arthritis. Usually the diagnosis can be made following aspiration. To avoid opening the hip joint needlessly. this differentiation must be made by this method.

Iliopectineal Bursitis. Lying between the hip joint capsule and overlying muscles anteriorly is a bursa which frequently communicates with the hip joint and which is rarely separately involved in a bursitis. If it is, incision and drainage with a rubber drain into bursa for a few days will usually suffice.

Peri (Deep Trochanteric) Bursitis. Chronic inflammation of this bursa is sometimes tuberculous in character. If not acutely inflammed, the aspirated material should be cultured for the tubercle bacillus and a guinea pig inoculation done.

Complete excision of the bursal sac in the chronic cases usually is necessary. If acute, one must aspirate, and in all cases the appropriate antibiotic should be given before and after surgery.

ward and backward descent in relation to the neck. In the traumatic type the deformity *is usually unilateral*, whereas *in the endocrine type it is more frequently bilateral.* This displacement *may* be very slight and very gradual, although it can be detected by roentgenographic examination quite early. The femur becomes outwardly rotated, and in the untreated cases the epiphysis is severely displaced; the articular cartilage rarely undergoes avascular necrotic changes in the early stage.

Treatment. As the condition is seen in adolescence it must be remembered that the patient will have some years of growth and probably further *slipping before the epiphyses normally fuse. Actual reduction* of the displaced epiphysis is desirable. In the Negro race the prognosis for full restoration of function appears to be poor.

The treatment of a patient with a history of recent displacement and demonstrable movement of the epiphysis radically differs from that of a patient having the displaced epiphysis firmly malunited by bony union.

In the first type (acute slipping) closed reduction, *gently done,* should be attempted and the results checked by anteroposterior and lateral roentgenograms. If satisfactory, *the reduction is held by a Smith-Petersen flanged nail inserted by the so-called "blind method" of nailing* through the greater trochanter, neck and epiphysis. When gentle manipulation succeeds in reducing the downward and backward slipping of the head, one may elect to put the limb in internal rotation, abduction and extension and hold it by a plaster of Paris spica (Whitman position), rather than to use any internal fixation. The younger the patient, the more internal fixation is mandatory.

In the second type of case (chronic slipping) *in which malunion* has occurred, an open operation should be done without attempting manipulative reduction. This consists of a curved osteotomy at the malunited area in the neck of the femur, a small wedge being removed from the superior and anterior portion of the neck. After reducing the slipping the cut surfaces are approximated and held by some type of *internal fixation* — screw, pins, *nail* or bone *graft. Sometimes* an osteotomy of the femur just above the level of the lesser trochanter in the older cases seems desirable as an alternative method, because this corrects the outward rotation This does improve the appearance when walking but does not change the underlying relationship of the slipped epiphysis on the neck of the femur

Slipping of the upper femoral epiphysis is a very *serious* condition. Following the reduction and pin fixation method, it is not necessary to

the gluteus muscle or the iliotibial band slipping backward and forward at the greater trochanteric region. This may even occur sometimes when the limb is moved passively. This noise is very disturbing to the patient and may be increased by actively contracting the muscular tissues about the hip. It is not usually painful, but to cure the condition the surgeon should divide the snapping band and sew it securely to the underlying tissues behind the greater trochanter.

FRACTURES

In comparing the attitude of the medical profession towards fracture of the hip one hundred years ago with the present, it is interesting to note the tremendous progress that has been made in the treatment of this disability. This type of fracture presents so many difficulties and problems that it becomes necessary today when discussing hip fractures to define not only the anatomical location of the break in the femoral head or neck, but also the age of the patient and the mechanism of its production — each having its own special value in the prognosis. In addition, one must appreciate the soft tissue damage the patient suffered at the time and shortly after the fracture was produced. At times, the initial injury to the capsule and vascular disturbance at the local site may irrevocably set the stage for nonunion or head necrosis later.

Today, however, results have so universally improved in fractures of the hip that we should direct our efforts to improve results in the capital region. Those at the base of the neck and in the transcervical region are receiving better treatment, with frequent bony union and good function the result. It would seem safe to state today that four out of five of these neck and base of neck fractures of the femur which have received anatomical reduction and internal fixation proceed to a satisfactory functional result, a fact entirely impossible some years ago. Critical analysis of hip fractures permits the term "unsolved fracture" to increasingly become a discarded and obsolete term, although late arthritic changes and head necrosis still occur too often.

No fracture can be successfully treated in 100 per cent of the cases but as the more standardized methods of treating the intracapsular fracture diffuse through the profession the results improve. The basic principles are early and accurate reduction; firm fixation of the fracture fragments by operation, and delay of weight bearing until the roentgenograms show bony trabeculae across the site of the fracture. These principles must be followed.

Ischiogluteal Bursitis (Weavers Bottom). This bursa lies between the tuberosity of the ischium and gluteus maximus muscle, so that when involved sitting is painful. Usually conservative treatment is sufficient; occasionally incision and drainage becomes desirable.

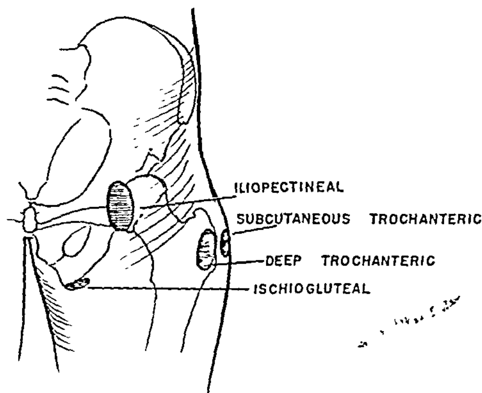


FIGURE 262. Bursae in the hip region

Traumatic Synovitis

The hip joint does not lend itself to a careful localization of increased joint fluid, and aspiration is occasionally indicated. The patient with traumatic synovitis presents a limp and muscle spasm and the hip is held in a flexed, abducted and externally rotated attitude, with negative roentgenographic and aspiration findings.

The treatment for both acute and chronic cases is local heat, rest and aspiration (see Fig 246). This will hasten absorption of the fluid, but a simple acute traumatic synovitis will usually clear up rapidly with bed rest and diathermy.

Snapping Hip

Occasionally one may find that when the thigh is voluntarily flexed and adducted there will be a snapping about the lateral surface of the thigh on movement. This snapping is caused by the fascia slipping over

times. The reduction should be early and complete in order that a deformity of coxa vara (see Fig. 256) does not result.

The Whitman abduction method of treatment (see p. 420), consisting of wide abduction, full extension and internal rotation, in the fresh case can easily be applied to these children and is effective and satisfactory (Whitman, 1891). The spica should be worn for a period of 3 months.

In the late untreated cases with the development of a marked coxa vara and shortening of the limb, a wedge osteotomy of the neck of the femur with the base outward and anterior is easily done and satisfactorily corrects the deformity, but does result in a slight shortening of the limb. In either case, those reduced early by the Whitman abduction method or those needing operative correction of the old malunion by a wedge osteotomy, the patient must wear a plaster spica for several months, after which weight bearing may be carefully resumed. Massage and active and passive movement are useful later to restore function to the hip joint.

Femoral Neck Fractures in Adults

Certain factors cannot ever be completely controlled, and while this type of fracture occurs in childhood and young adulthood, the greatest difficulty is encountered in elderly, undernourished patients, who tolerate inactivity badly and who will always be subject to fracture of the hip. The state of deficient nutrition and normal inactivity in the aged patient is always a great problem, but recognition and adequate care of the geriatric patient have made great advances in the past few years, particularly in the over-all treatment of fracture of the hip.

Fracture of the neck of the femur occurs most frequently after the fourth decade and Childress (1957) has recently reported 3 patients over 100 years of age. The fracture is associated with a very slight injury such as a sudden twist of the body, tripping over a rug or falling. These fractures were formerly regarded as intracapsular or extracapsular, the displaced intracapsular fractures presenting the greatest problem; however, they can better be classified according to their anatomic location by dividing them into four classes according to the site of fracture in the bone: the subcapital, transcervical, cervicotrochanteric and pertrochanteric (Fig. 264).

One may also use the terminology of Watson-Jones and classify the neck fractures into two types: the *adduction* (the usual type) and the abduction. In the adduction type of fracture the shaft and neck of the femur are adducted in relation to the head, giving rise to a shearing

Femoral Neck Fractures in Children

Fractures of the neck of the femur may occur at any age, but during certain age periods it is more commonly noted. In children it is not a particularly rare finding, and since 1890, when Whitman focused attention to the subject by introducing the abduction treatment, a number of cases have been reported in children of all ages. The transcervical type of fracture may be seen, but the more common type is the so-called

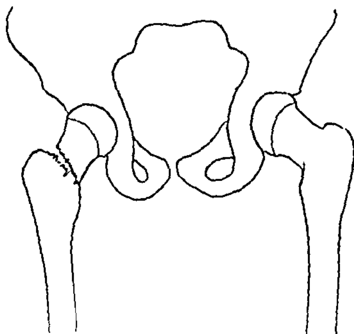


FIGURE 263 Hinged type of fracture. This hip fracture is most frequently seen in children.

hinge or greenstick variety, which occurs in the cervicotrochanteric region, and is not a complete fracture (Fig. 263). These fractures are far less disabling in the child than in the adult. The trauma necessary to produce a fracture of the neck of the femur in childhood is of a more severe and violent type than in adults. Usually the child falls from a great height or is dragged by an automobile and suffers a severe bruising. The immediate disability is not so severe as in the adult, although the deformity tends to increase if not properly treated. The child may sometimes even be able to walk following the injury, but careful examination will show a limitation in hip motion and shortening of the limb. The leg is usually in some degree of outward rotation and the roentgenographic examination will confirm the diagnosis.

Treatment. Nonunion occurs very rarely with these fractures in childhood, although avascular necrosis has been reported a number of

the affected side; in these cases the tuberosity will be above Nélaton's line, and Bryant's line will be shortened as compared with the normal side. One should not prolong the examination by looking for crepitus or abnormal mobility. The patient should be fitted with a traction splint at the site of the accident, if possible, and removed quickly to the hospital



FIGURE 265. Impacted transcervical fracture of the hip.



FIGURE 266. Femoral neck fracture of right limb. Note shortening and marked outward rotation of limb.

force which is a factor in producing nonunion. In the abducted type this frequent cause of nonunion is reduced to a minimum.

The *impacted fracture* is a happy happenstance when it occurs and is the one type of hip fracture that must be recognized early and not

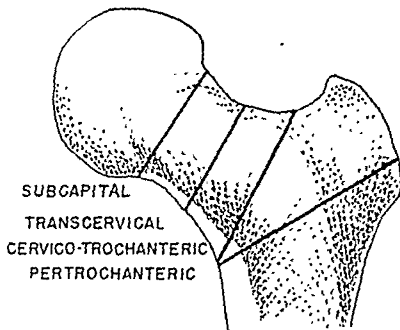


Figure 264. Delbet's classification.

subjected to any manipulation when fixed to the neck by impaction (Fig. 265). It is the one type of subcapital fracture that has a good prognosis. Due to the slight disability it is sometimes overlooked. One may immobilize these fractures by internal fixation, such as by bone graft, Moore pins or a large type of screw, but usually this is not necessary. The Smith-Petersen nail is not recommended, as its insertion may break up the impaction or displace the fragments. Cautious, partial weight bearing may be begun with crutches after a few weeks of bed care. These patients will rapidly progress and hip and ankle motion should be begun quite early, with the expectation of excellent functional mobility and solid bony union.

Clinical Picture. These patients are usually severely incapacitated unless the fracture is an impacted one. They lie with the affected joint *in excessive external rotation, complain of acute pain on motion and* present an obvious shortening of the limb (Fig. 266). If the fracture is not impacted, it is impossible for the patient to raise the heel from the bed, and the whole extremity lies helpless. Measurements from the anterior superior spine to the internal malleolus show a shortening on

operator's hand after the reduction just described has been effected; if reduction is satisfactory, the position of the foot will be unchanged; if not, the limb will slowly assume its outward rotated attitude while resting on the outstretched palm. This, however, is not always a reliable test and both anteroposterior and lateral roentgenograms should be routinely employed to determine if the reduction is successful.

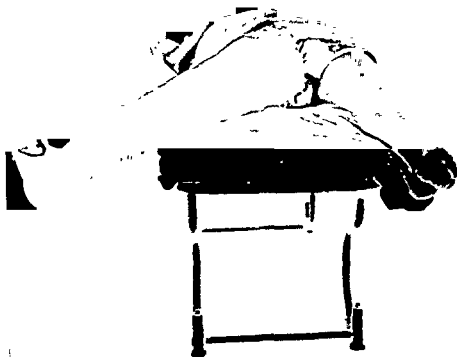


FIGURE 267. Whitman abduction method of immobilization.

In both the Whitman and Leadbetter methods the limb is immobilized in a plaster spica in wide abduction, internal rotation and full extension. The patient should be turned over daily to lessen the opportunity for pulmonary and skin-pressure complications. Raising the head of the bed on shock blocks is recommended to make the patient more comfortable. When this method is adopted, the limb should be supported in an abduction plaster for 6 to 9 months if healing is progressing satisfactorily. This can be determined by roentgenograms taken at 3 month intervals, reapplying a new plaster if the original spica becomes loose. Crutches, with nonweight bearing on the limb, may be allowed after the fourth month. Usually a patient treated by the regular Whitman method should not be regarded as completely out of the surgeon's

where roentgenograms must be taken. If the patient's general condition permits, immediate treatment of the fracture following the roentgenographic examination should be done. The preoperative roentgenogram should consist of a simple anteroposterior view, and upon this and the clinical examination a prognosis can be based as follows: If the fracture involves the subcapital region, the prognosis for bony union is always poor, whereas in the cervical, cervicotrochanteric or pertrochanteric regions the prognosis for bony union becomes progressively better.

Any elderly individual who complains of sudden pain and disability in the hip following a fall should be regarded as having a fracture of the hip until it is proved otherwise. These may be caused by a local pathologic process, such as a metastatic lesion plus trauma, or by local trauma alone.

Treatment of Capital, Subcapital and Transcervical Fractures. *Early and accurate reduction is essential.* Reduction should be accomplished as early as possible, and this is the crux of the treatment of fractures with any method one elects to follow. The postreduction roentgenogram should disclose the fact that the fracture has been as completely reduced as possible in both anteroposterior and lateral views. This is the one type of fracture that requires accurate reduction, as verified by these two views, if bony repair is to be anticipated.

Closed reduction. The Whitman method, with the Leadbetter modification, may be regarded as the most satisfactory closed method of treatment.

The Whitman method consists of having the patient under anesthesia on a fracture table. Traction is manually made on both lower extremities simultaneously against a well-padded perineal bar. The surgeon then places the fingers of one hand behind the greater trochanter of the fractured hip and the limb is rolled inward, rotating the shaft of the femur inward with the other hand while both limbs are simultaneously widely and equally abducted by assistants. A single plaster spica is then applied from the axilla to the toes with the injured hip in marked inward rotation (20 to 30 degrees), abduction and complete extension, the knee in slight flexion and the foot at a right angle to the leg (Fig. 267).

The modification suggested by Leadbetter consists in flexing the injured hip and lifting upward on the flexed knee to reduce the hip fracture, then internally rotating slowly, extending and abducting the hip. If the fragments are locked, he recommends the "heel palm" test. This consists in resting the heel of the foot in the palm of the

patient to a more extensive operation, but it has the advantage of visually reducing and pinning the fracture. Following any of the above operative nethods, no plaster is applied, or, if applied, only for a short wound-healing period of a few weeks. On removal of the plaster spica

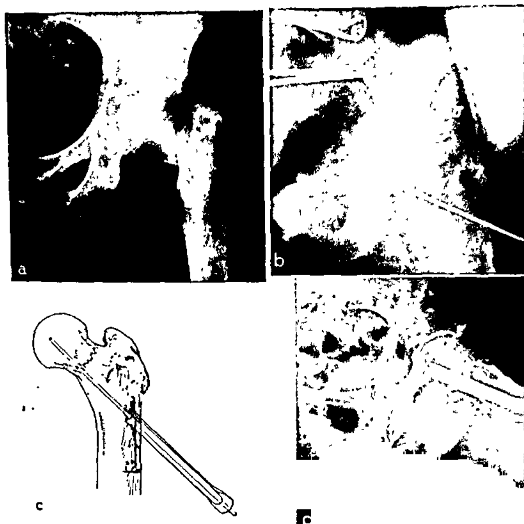


FIGURE 268 Four stages in reduction and immobilization of a transcervical fracture of the hip, using a Smith-Petersen nail.

the limb is supported by a Thomas splint with an overhead Balkan apparatus to permit early motion of the hip in bed. The patient, if no temporary plaster is used, can be placed in a wheel chair a few days after the operation if it seems advisable, and then allowed up on crutches gradually. However, no weight bearing is permitted until bony union is assured and proved by anteroposterior and lateral roentgenograms, and this is usually a minimum period of 6 months. We usually

supervision for at least a year after reduction and plaster application.

Whether one elects to follow the nonoperative or operative methods, the fracture must be accurately reduced before immobilizing the hip by plaster, and this is very difficult to confirm. The principles upon which the abduction technic of Whitman is based are sound; if the fracture is accurately reduced and the plaster spica accurately applied and carefully watched, it affords an excellent opportunity for satisfactory union. Unfortunately, the original damage done in the *capital* and *subcapital* types is so great that bony union rarely occurs and unless these fractures are impacted (p. 418) the author prefers early removal of the head fragment and a reconstruction operation, or, in the elderly patient, an intramedullary prosthesis. With the other types, the prognosis is better.

Open reduction. Because many of these elderly patients do not tolerate a long period of immobilization in plaster, two methods of doing an open operation have been evolved.

(1) Following *accurate closed reduction* of the hip a small lateral incision is made over the greater trochanteric region. A guide wire is then inserted obliquely through the shaft and across the line of fracture into the head fragment, checking with anteroposterior and lateral roentgenograms during the operation. Then the Smith-Petersen flanged nail is threaded over the guide wire, through the neck and into the head of the femur, checking its course by roentgenograms (Fig. 268). This has been called "blind nailing" and should be used only if preoperative roentgenograms show an accurate anatomical reduction. Occasionally local anesthesia for the aged or poor-risk patient is advisable.

(2) Reduction of the fragments can be more accurately done under the eye of the operator through a somewhat larger exposure (Smith-Petersen or Watson-Jones approach) in which the capsule is exposed and opened The fracture fragments can then be visualized and manipulated into position. After accurate reduction by manipulation is accomplished, some type of internal fixation is used. This fixation may be attained by the use of a Smith-Petersen nail, a lag screw type of nail, Moore pins, cortical bone grafts or the sliding nail of Pugh or Badgley. The nail or pin is driven through the femoral shaft and neck and into the head fragments as shown in Figure 268, using a guide wire usually. The author prefers the Smith-Petersen nail for internal fixation.

The second procedure has the disadvantage of subjecting the elderly

tion. The Compere-Albee table is preferred by the author, the patient being so arranged that roentgenograms can be obtained without moving him. The limbs are immobilized by longitudinal traction with the feet fastened to foot plates. Measurements from the anterior superior spine to the internal malleolus on each side are checked before the operation is begun and more traction applied as desirable. If the shortening and external rotation has been satisfactorily overcome, the surgeon makes a Watson-Jones incision. A Kirschner wire is than inserted 1 or 1½ inches below the lower edge of the greater trochanter and directed obliquely upward through the femoral shaft into the neck and head. At this time anteroposterior and lateral roentgenograms are made without moving the patient. Then a nail plate — the author prefers the Neufeld-angled nail — or the Smith-Petersen and McLaughlin attachment is inserted; the plate is attached to the femoral shaft by at least three screws (Fig. 269). This restores the shaft-neck angle of approximately 128 degrees. Unless there is severe comminution, the nail plate will immobilize the fragments in good position. Following the wound closure, the author likes to immobilize the patient in an unilateral spica for 2 or 3 weeks and then start nonweight-bearing activities in bed, followed shortly after by nonweight-bearing exercises in a walker. No bearing of weight is permitted until the roentgenograms reveal solid bony union; the roentgenogram is the criteria and not the calendar in treating all fractures of the hip.

Closed reduction. Careful attention to the application of true Russel's traction gives a most satisfactory result in the treatment of comminuted intertrochanteric fractures. Occasionally, the Roger-Anderson leg traction is suitable when other methods are not feasible.

In all traction methods, constant supervision is needed. Russel's traction may be the method of election, but it does not allow these elderly patients to be turned or permit freedom of movement in bed. It is surprising, however, that if this traction method described so carefully by Russel can be carried on for 3 or 4 weeks, sufficient callous is usually present at the site of fracture to safely apply a plaster spica. This will allow daily turning and is of great advantage.

The maintenance of the neck-shaft angle of 128 degrees must be preserved if at all possible, but in the unstable type of fracture, with the pulverized bone often found in the severely comminuted type, the angled nail will not hold securely. In these instances, if traction is not suitable in correcting the varus, the Dickson geometric osteotomy has been later employed.

advise the patient that full weight bearing and activity be delayed for 12 months following a transcervical fracture of the hip.

Cervicotrochanteric and Pertrochanteric Hip Fractures

In general, these femoral neck fractures are treated too casually. They are usually caused by a fall such as a direct injury against the hip region. The forces of shearing stress and strain present in capital and transcervical fractures are less here and a low mortality rate is usual. Accurate reduction can be obtained much more easily than in the types of fracture near the head. Only when there is severe comminution is the nail-plate method unable to securely stabilize the bone fragments in good position. Evans (1951) reviewed 110 cases and has divided the fractures of this region into the stable and unstable types, feeling that the stable type shows continuous apposition along the calcar femorale after reduction and fixation. In his series, the stable type constituted 71 per cent of these fractures; the unstable type, where reduction could be obtained only after careful and repeated manipulations, formed 23 per cent; and those that presented so much comminution that a coxa vara deformity was the end result made up only 6 per cent. Therefore, only a very small per cent of these fractures should give a poor result. Cram (1955) reviewed 60 cases and felt that about 90 per cent were of the stable type, but he warned that a stable fracture could be converted into an unstable one by excessive preoperative traction.

Clinical Picture. These fractures occur more frequently than the capital or transcervical types and are usually the result of a direct force in contrast to a tortional force seen in the transcervical fractures. The patient, who is usually an elderly individual, presents a picture of helplessness with external rotation, rather severe pain and shortening of the injured limb, and should be treated as promptly as possible. Good roentgenograms are essential, but if delay is unavoidable, a Buck's extension of 12 to 15 pounds for 24 hours will make the patient more comfortable.

Treatment. *Open reduction* and nail-plate fixation is the method of choice. The sandbag method of treatment is to be condemned. Reduction can also be obtained by using Russel's traction for 8 weeks. A *satisfactory* union can be expected in an open operation. *Coxa vara* deformity is a common sequelae. Inhalation anesthesia is preferable when an open operation is done.

The fracture is reduced on the operating table by longitudinal trac-

Solid bony union, as checked by the roentgenogram, is the rule rather than the exception, but nonunion does occur. Coxa vara may be very commonly seen, whatever the method of treatment used, provided weight bearing is allowed before bony union is complete. With pin-plate fixation, one must depend for stability upon bony union at the site of fracture and not upon the stability of the plate.

Fracture of the Greater and Lesser Trochanter

These injuries follow a fall. At the greater trochanteric area the displacement is caused by direct violence. The fracture of the lesser trochanter is produced by a violent muscle contraction of the iliopsoas. They are both rare injuries and are accompanied by local tenderness at the insertion of the gluteus medius or iliopsoas muscle respectively. The hip is held in a flexed or adducted position depending on the area injured and any attempt at movement is very painful. A roentgenogram should be taken as early as possible.

Treatment. Treatment consists in keeping the patient in a recumbent attitude in bed. In the greater trochanteric injury, the limb is kept in extreme abduction for 3 or 4 weeks; with fractures of the lesser trochanter, the limb is held flexed and inwardly rotated in plaster for 4 weeks. Very rarely is open operation indicated in either of these fractures.

REHABILITATION FOR THE UNUNITED HIP FRACTURE

Under this classification are included those cases with delayed union or frank nonunion with or without an avascular necrosis of the femoral head. All fractures of the neck of the femur in adults heal slowly, for at best the circulation in this area is poor; however, inadequate fixation, improper reduction, advanced age, too early weight bearing, or interposed tissue always make delayed union or nonunion a likelihood. The type and location of the femoral neck fracture may also be a factor in the development of nonunion; an oblique neck fracture or one involving the head or subcapital region is prone to nonunion.

Under the best of treatment probably not over 20 per cent of fractures of the capital and subcapital regions heal with bony union, but a considerably higher percentage heal with bony union in the transcervical and cervicotrochanteric regions.

It is in cases with delayed union in which previous reduction and

Too early weight bearing must be cautioned against, for it will result in development of a varus deformity. Weight bearing is not advised

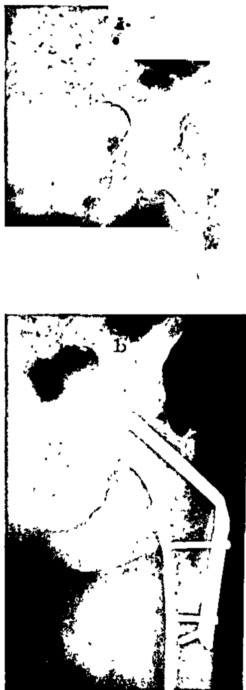


FIGURE 269. Intertrochanteric fracture: *a*, before treatment; *b*, after treatment with an angled nail. This is an excellent method for treating the majority of intertrochanteric fractures.

under 4 to 6 months after reduction, but again the roentgenographic evidence is the best criterion to decide this and not the time interval.

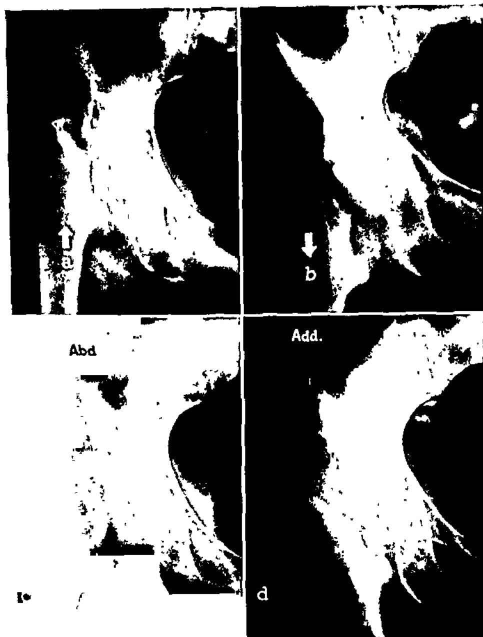


FIGURE 270 Methods of determining nonunion: *a*, push; *b*, pull; *c*, abduction; and *d*, adduction.

Delayed Union

In fractures of the neck of the femur, healing is always slow so that further immobilization or further restriction of activity may convert a delayed union into a bony union. As long as roentgenographic evidence shows that repair is progressing in these fractures, operation is rarely indicated. However, the two operative methods given below may prevent delayed union from advancing into nonunion.

Drill holes, using small drills or Kirschner wires, are made through

immobilizaton have been satisfactory that the problem of (1) further immobilization and (2) the time to begin weight bearing becomes a very difficult question to answer. Certain clinical and roentgenographic criteria are useful aids in determining evidence of bony union, but hip fractures in general are still most unpredictable.

Methods for Determining Delayed Union and Nonunion

In the case of frank nonunion the diagnosis is often self-evident, for the severe disability caused by the telescoping at the hip when the patient bears weight on the limb is striking. With this insecurity, shortening, and often severe pain, the limb assumes a flexed and adducted attitude and the greater trochanter can be seen and felt above Nélaton's line. The roentgenogram also presents evidence of nonunion (Fig. 270).

Clinically, in certain instances, depending upon the amount of local trauma at the time of injury and at the time of reduction, absorption of the neck may be rapid. As a rule, however, at least several months will elapse before the roentgenograms will give evidence of nonunion At this time it must be determined (1) whether the head simultaneously moves when the shaft is gently rotated; (2) whether there is any telescoping of the thigh, when the telescoping maneuver is gently attempted (Fig. 270a, b); (3) whether the greater trochanter is above Nélaton's line; (4) whether there is a disproportion between Bryant's line on either side; and (5) whether the measurements from the anterior superior spine of the ilium to the internal malleolus are approximately equal. Having determined these findings by clinical examination, roentgenograms should be taken in (1) both anteroposterior and lateral views, (2) in adduction and abduction and (3) sometimes a push-and-pull plate (see Fig. 270). A careful study of these films should reveal if there is motion at the site of the original fracture — another evidence of nonunion. The roentgenograms may be of great prognostic aid for they will reveal (1) the degree of displacement, (2) the degree of neck absorption and/or head necrosis, (3) the width of the joint space, (4) the presence of arthritic changes in and about the hip joint and (5) the presence or absence of bony trabeculae extending across the site of the fracture.

All of these findings must be routinely observed and evaluated to make a decision regarding whether the particular case is progressing satisfactorily or whether there is delayed union or frank nonunion. The information gained from the roentgenograms will in large part determine the type of treatment to be recommended.

outline will frequently develop and a narrowing of the joint space which means joint cartilage destruction; these are forerunners of arthritic changes in the joint.

Complications. Avascular necrosis must be feared as a late complication in some cases of neck fracture even with solid bony union. Reports from large fracture clinics show that a smaller percentage of *nonunion* is being obtained today, but an increase in the development of *avascular necrosis* and *arthritis* of the joint is being noted. These latter are unpredictable and disabling complications and occur in about one-third of intracapsular fractures.

Treatment. Always the decision as to the *viability of the head fragment* is of major importance, for the preservation of the component parts of the ball-and-socket joint is always necessary to obtain normal motion. The *joint space* must be of a similar width to that of the normal hip joint for one to assume preservation of the articular cartilage covering the head and acetabulum. If the joint space is normal and there is no evidence of avascular necrosis, any operation that will be followed by bony union between the head fragment and the neck of the femur will assure the preservation of a good range of motion. The Smith-Petersen nail or Moore pins or bone pegs are devices usually reserved for the fresh fracture cases or those with delayed union. In those with frank nonunion and extensive neck absorption, the commonly used procedures are osteotomy, various types of reconstruction operations and prostheses.

Osteotomy. In order to change the line of weight bearing in these ununited femoral neck fractures and in order to place the long axis of the femoral shaft directly beneath the pelvis and eliminate the shearing action at the site of the fracture line, two types of the osteotomy (Fig. 272) are used. (1) The high osteotomy (McMurray osteotomy), in which the femur is severed by a slanting upward cut dividing the bone just proximal to the level of the lesser trochanter and displacing the distal femoral shaft medially beneath the head of the femur, eliminates the shearing action at the old fracture site and union is induced between the head and the osteotomy site. (2) The low osteotomy (Schanz osteotomy) divides the femoral shaft at the level of the tuberosity of the ischium.

The advantage with these procedures is the lack of shock to the patient; as a rule the elderly patient is not a good surgical risk and these short operative procedures are desirable. These osteotomy operations are often able to convert an unstable, painful hip into a stable,

the greater trochanter into the neck and head, permitting fresh channels to be opened up for increased blood supply, thereby hastening union.

Internal fixation by certain types of pins or nails or even bone grafts provides both immobilization of the fragments and increased blood supply may be obtained. Firm fixation always permits healing to be hastened. Occasionally, even after fracture healing, necrosis of the femoral head may occur (Fig. 271).



FIGURE 271. Partial avascular necrosis of the femoral head.

Nonunion

This can be easily demonstrated both clinically and by roentgenograms as described. The instability, pain and shortening are all outstanding features of femoral neck absorption. Accompanying or preceding absorption of the neck in whole or in part, avascular necrosis of the head fragment may develop. A careful study of the roentgenogram shows whether the femoral head has undergone avascular (aseptic) necrosis; when this occurs the head may be noted to produce a denser shadow than the adjacent bone structure. Decalcification of the head fragment indicates active vascularization, but the whitish dense head indicates a lack of blood supply and necrosis (see Fig. 271) as pointed out by Santos (1930). Along with this bone death an irregularity of

A double spica plaster is worn for 8 weeks, after which weight bearing is gradually begun.

(3) The Dickson reconstruction (Dickson, 1947) is a high geometric osteotomy through the greater trochanter and neck region, which changes

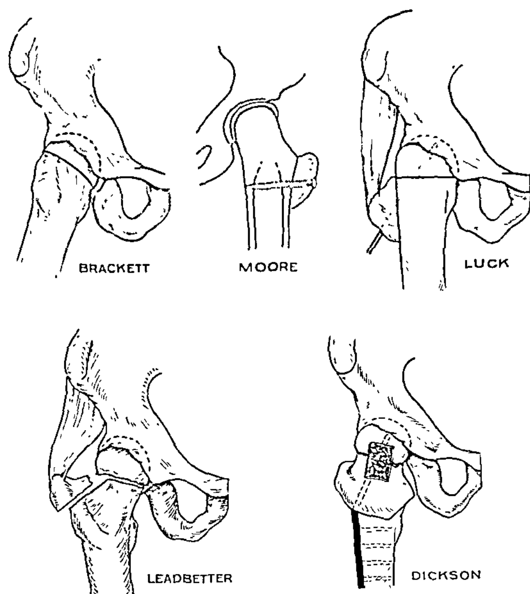


FIGURE 273. Reconstruction operations for ununited fracture in which the head is viable and should be retained

the lines of force and makes the body-weight thrust at 60 degrees to the fracture line. This changes the factors of shearing stress and strain into a compression force at the site of fracture and stimulates healing of the fracture.

(4) The Leadbetter reconstruction (Leadbetter, 1944) is a high osteotomy within the capsule area.

painless one. The disadvantages are the resulting limitation of motion and a little more shortening of an already short extremity. Also bony union at the site of these osteotomies must follow for the operations to be successful. The author is of the opinion that the McMurray osteotomy is a very valuable procedure.

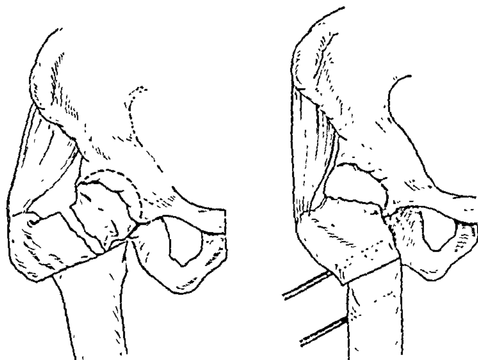


FIGURE 272. Types of osteotomy: *Left,* McMurray (high); *right,* Schanz (low).

Reconstruction operations for cases with viable head fragment (Fig. 273). (1) The Brackett reconstruction (Brackett, 1925) consists in preserving the femoral head, which is denuded of fibrous tissue on its neck portion and sometimes hollowed out. Then the upper extremity of the distal fragment is remodeled and these two raw surfaces approximated. A portion of the greater trochanteric area with its attached abductor muscles is transplanted downward on the shaft of the femur and a plaster spica applied until union at the head fragment can be proved by roentgenogram.

(2) The Luck reconstruction (Luck, 1938) operation preserves the femoral head but removes a wedge-shaped mass of bone from the base of the neck on the femur. Following this procedure, the head fragment is denuded and the shaft and head are approximated. The greater trochanter with its attached muscles is transplanted downward and a Steinmann pin transfixes the greater trochanter, shaft and head fragment.

trochanter and its attached muscles from the femur, making the bone cut in line with the superior surface of the neck. The head is removed and the cut surface of the femur is placed within the acetabulum. The greater trochanter and muscles are transplanted downward on the shaft. A plaster spica is worn for 4 weeks. Then active and passive exercises are begun in bed, and weight bearing is started a few weeks thereafter.

(2) The Albee reconstruction (Albee, 1929), splitting the upper end of the femur longitudinally and prying the bone flap laterally, results in increased leverage of the attached abductor muscles. The head of the femur is removed and a portion of it wedged in the cleft, as shown in Figure 274. A plaster spica is applied for a few weeks.

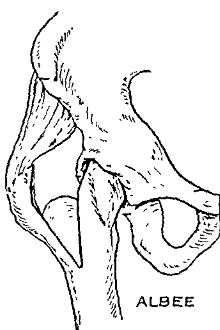


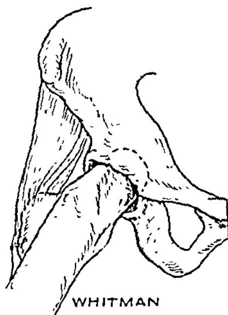
FIGURE 275. Oblique view of hip, to show depth of acetabulum and width of joint space. The patient is placed for a lateral view of the lumbosacral joint and then tilted forward 17 degrees from this point.

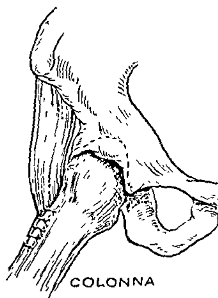
(3) The Colonna reconstruction (Colonna, 1935) is recommended in cases with complete or almost complete neck absorption, and in those with avascular necrosis of the head and marked shortening. This operation has the advantage of giving stability, mobility and restoration of some length, but the acetabulum must be of normal depth (Fig. 275) and show no arthritic changes.

(5) Moore (1948) preserves the head fragment and hollows it out until the cartilage cup remains, placing this over the reconstructed upper extremity of the femur. The greater trochanter with its attached muscles is transplanted downward on the shaft of the femur.

Reconstruction operations when head is not viable and its removal is necessary (Fig. 274). (1) The Whitman reconstruction (Whitman, 1921) is frequently employed. It consists of separating the greater







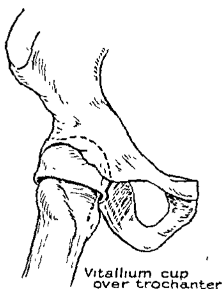


FIGURE 274. Reconstruction operations for ununited fractures in which the head fragment has undergone avascular necrosis and must be removed.

(5) Arthrodesis of the hip following nonunion of the neck of the femur has a very limited field. As a rule motion and stability can be obtained either by the osteotomy or by one of the reconstruction operations. Arthrodesis of this joint in elderly patients is not easy to attain and is rarely necessary, but sometimes such an operation may be done to relieve persistent pain from arthritis of the joint.

Prosthesis. Since the report in 1955 by Judet discussing the use of acrylic prostheses in hip surgery in 789 cases, the results have been studied carefully. It is fair to state that for the ununited hip fracture the results obtained by the use of the Judet acrylic stem prosthesis have in general failed to come up to those originally expected. More careful selection of cases has given better results, but the persistent pain factor and the feeling of insecurity when the reconstructed hip is subjected to laboring conditions have, in the author's experience, been the main drawbacks to the procedure.



FIGURE 277. Fred Thompson intramedullary prosthesis *in situ.*

In patients presenting complete neck absorption and head necrosis the intramedullary stem type of metal prosthesis and various plastic substances have been used as well as the acrylic prosthesis of Judet. The Fred Thompson vitallium intramedullary prosthesis (Fig. 277) has been used most successfully in the elderly, nonlaboring type of

The abductor muscles are dissected free from the greater trochanteric region without denuding any of the underlying bone. Then the capsule is divided, the head removed, and the greater trochanteric region freed of all its muscular attachments from the pelvis down to the level of the lesser trochanter. Any nubbin of neck found is completely removed, all raw bone is covered with adjacent soft tissue, and the tro-



FIGURE 276 *Left*, avascular necrosis and nonunion previously treated by metal fixation. *Right*, same hip 8 years postoperatively following trochanteric reconstruction operation.

chanter is placed within the acetabulum (Fig. 276). The abductor muscles are then reattached downward into a bony trough on the lateral surface of the shaft. The limb is kept in abduction in a plaster spica for 4 weeks, then for the following 2 weeks active and passive motion is begun in bed with the limb in balanced suspension. Weight bearing is gradually assumed 6 to 8 weeks after operation.

In recent years the failures following the use of the Judet prostheses and various form of intramedullary prostheses have posed serious problems. This trochanteric reconstruction operation permits many of these hips to be salvaged (see Fig 276).

(4) A modification of the Colonna and Whitman reconstruction operations has been described by Smith-Petersen *et al.* (1947) and by Wilson (1947) respectively, consisting of the insertion of a vitallium cup over the upper end of the femur.

and often felt under the posterior gluteal muscles. A roentgenogram (Fig. 278) should be made at once to determine the exact postion of the femoral head and also to decide if the dislocation is complicated by an associated fracture of the head or articular lip of the acetabulum (Fig. 279).



FIGURE 279. Dislocation complicated by a fracture of the posterior lip of the acetabulum.

Treatment. If the case is one of simple dislocation, early reduction should gently be attempted under general anesthesia. The simplest method (Fig. 280) is to place the patient on the floor in order to permit proper leverage and reduction. The assistant holds the pelvis with his hands in order that the operator may apply the force directly to the hip joint. The affected hip is then flexed, thereby relaxing the iliofemoral (Y) ligament, and the femoral head is passively lifted upward toward the acetabulum. Reduction is then accomplished by gently adducting and rotating the limb while the traction is applied upward in the flexed and adducted attitude. Reduction is often accompanied by a sharp snap as the hip slips into place. The limb can then easily be moved into abduction, external rotation and extension.

individual. To this type of sedentary patient the ability to sit comfortably, to lean over and tie shoe laces or pick up objects from the floor and to walk short distances with little or no pain has been a boon. The vigorous elderly man or woman who wishes to be active, or any individual under 65 who leads an active outdoor existence, primarily wishes stability and they have not usually been satisfied with the prosthesis operation, although a few exceptions to this have been found.

DISLOCATIONS

Posterior Dislocation

Traumatic dislocation of the hip is usually posterior in type, the dislocation being initiated by indirect violence when the hip is flexed to 90 degrees and adducted.



FIGURE 278. Simple posterior traumatic hip dislocation.

The posterior dislocated position is characterized by adduction, internal rotation of the thigh and slight flexion of the hip. Definite shortening of the limb is noticeable and the head can be observed

Fracture-dislocation

A *"dashboard" type of fracture-dislocation* occurs when the knee is violently struck against the automobile dashboard, jamming the head of the femur backward, fracturing the acetabulum and dislocating the head. This results in posterior dislocation.

Treatment. If the dislocation of the hip is complicated by a fracture of a portion of the rim of the acetabulum, an open operation is often necessary and at this time the dislocation can be reduced (see Fig. 279). The fragment is replaced and held in position by bone pegs or



FIGURE 281. *Left,* fracture-dislocation of hip. *Right,* hip following fusion.

by some metal fixation. The severe types of fracture-dislocation may make reduction with restoration of painless function impossible. Here fusion of the hip may be the treatment of election (Fig. 281). Rarely should these fracture-dislocations be treated by closed methods; usually complete reduction of the hip into its normal position cannot be accomplished by closed reduction, and if attempted, late arthritic changes and great disability are apt to follow. *Paralytic dislocations of the hip* are mentioned under Infantile Paralysis (Chapter 15).

Sequelae

Dislocation of the hip produces severe trauma and considerable injury to the soft tissues. The sciatic nerve, because of its close relation to the femoral head, is sometimes injured in the posterior dislocation, also sometimes in too vigorous methods at closed reductions.

After reduction the patient is advised against full weight bearing for 6 months to prevent the development of avascular necrosis.



FIGURE 280 Posterior dislocation of the hip Characteristic position of flexion, adduction and internal rotation (*a*) Method of early reduction (*b*) With the patient on the floor, upward traction on the flexed hip with the limb in adduction and gentle external rotation usually is effective in reducing the hip.

Anterior Dislocation

Anterior dislocation may be produced by violent hyperabduction at the hip, forcing the head out through a rent in the anterior inner portion of the capsule. The head in this case will then lie in the thyroid (obturator) foramen and may be converted into an anterior position by outward rotation of the thigh. When the thigh is rotated inward, it will be converted into a posterior dislocation, the usual type.

the public at large remains unanswered as no large series with definite statistical proof has been advanced, but neither condition is common, though probably the milder form of dysplasia, the subluxation, occurs more commonly.

Congenital dysplasia of the hip can be and should be recognized in the first 6 months of life, that is, before weight bearing. If even one true dysplasia is neglected or not recognized, permanent fixed deformity will result and a greater or lesser degree of lifelong disability occur.

Congenital Subluxation of the Hip

A clear-cut differentiation between the term subluxation and luxation in describing dysplasia of the hip was made some years ago by Leveuf (1947). It is believed that his method of differentiation by the use of arthrography as shown in Figure 282 is probably a sound one.

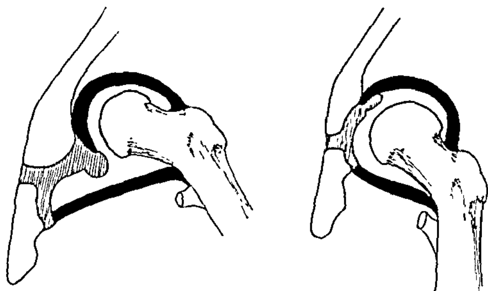


FIGURE 282. Anatomical difference between (*left*) luxation and (*right*) subluxation according to Leveuf, who states in subluxation the limbus is forced upward and inward toward the iliac fossa, whereas in luxation the limbus is forced downward toward the acetabulum.

He felt the differentiation was clear and expressed it as follows: "In subluxations, the limbus is forced upward and inward toward the iliac fossa, whereas in luxations, the limbus is forced downward toward the acetabulum." While a subluxation may progress to a true dislocation, this is not by any means the rule. In most subluxations the articular surfaces of the femoral head and acetabulum will continue to be in contact, while the reverse is true in the primary dislocated hip. Putti, as early as 1929, stressed the importance of early recognition and early

Late evidence of avascular necrosis of the head of the femur has been frequently reported following even the gentlest of reductions. At the time of the dislocation undoubtedly considerable damage to the circulation of the femoral head was produced, so that the possibility of subsequent necrosis and flattening of the head with or without a traumatic arthritis should always be kept in mind and the patient advised of these possibilities. Early weight bearing is a definite factor also in producing these sequelae.

HIP DYSPLASIA

Dysplasia, as the term is defined, includes any abnormality of hip development; therefore, it would include wide variations in development at the hip. The author accepts the belief that dysplasia is the result of an interruption of the normal growth forces of the hip joint. In what period this may begin is not known, but conceivably this interruption may be familial, genetic, mechanical, or possibly hormonal. In other words, we cannot explain all hip dysplasias on one etiological factor. One sees some cases with a definite familial background, some with no other structural abnormality, as far as can be learned, for generations past, some combined with cerebral paralysis and others with multiple congenital anomalies. The term dysplasia was first introduced in 1925 by Hilgenreiner, who recognized that subluxations and dislocations presented differences in character and degree.

That a long period of careful supervision will be necessary to treat any case of hip dysplasia should be explained to the parents. Although age is not the only factor in deciding upon the type of treatment most suitable, this concept lends itself to a satisfactory plan of treatment.

A variety of congenital anomalies involve the hip joint; even congenital absence of the hip joint has been reported. By far the most common, however, is a *congenital* dysplasia, of which there are two types: (1) congenital subluxation of the hip, and (2) congenital dislocation.

We know that the frequency of dislocations varies considerably in different countries and that in certain European countries, especially Italy and certain regions of France, dysplasia of the hip is more frequently found than in the United States. Von Rosen (1956) reviewed routinely 1200 babies with 17 presenting the Ortolani sign, a very small percentage of the total therefore presenting evidence of dysplasia. Whether subluxations are present more frequently than dislocations in

Limitation in abduction and *asymmetry of the thigh folds* (Fig. 284) are so frequently sought today by pediatricians that undoubtedly these signs have become widely recognized. One must remember, however, that these signs alone are not pathognomonic for subluxations.

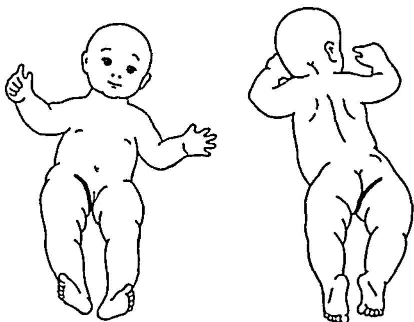


FIGURE 284. Dysplasia of the R hip. Increase in depth of the gluteal and inguinal folds are early clinical signs (V. Hart).

The *Ortolani "click"* is probably the most frequent finding in early dislocations and in certain subluxations, but simply because one does not find this sign in what otherwise appears to be a definite case of subluxation does not rule out the case being one of subluxation. Ortolani's test for the "sign of the jerk" was described as the "click of entry" and "click of exit."

Other congenital anomalies in body structure are also found accompanying the dysplasia, such as clubfoot, cleft palate, harelip, etc. It is particularly true that calcaneovalgus of one or both feet, or a metatarsus adductus of one or both feet may be frequently associated with subluxation of the hip. Rarely in the congenital subluxation of the hip does one see in the roentgenogram a measurable degree of lateral displacement of the upper end of the femur, but these signs are frequently seen in dislocations. The *sloping acetabulum* is undoubtedly one of the most common findings found in subluxation, but there are wide variations in the degree of this apparent instability. It is rather hazardous to give specific degrees indicative of subluxation in infants as the age factor does not always produce consistent results. The late

treatment of hip dysplasia, saying that, "One should begin treatment the moment the deformity is observed, even if it be on the day of birth."

Statistical reports show a much higher percentage of normal functional, anatomical and roentgenographic hips will result following early treatment of subluxation (Fig. 283) than of luxations.

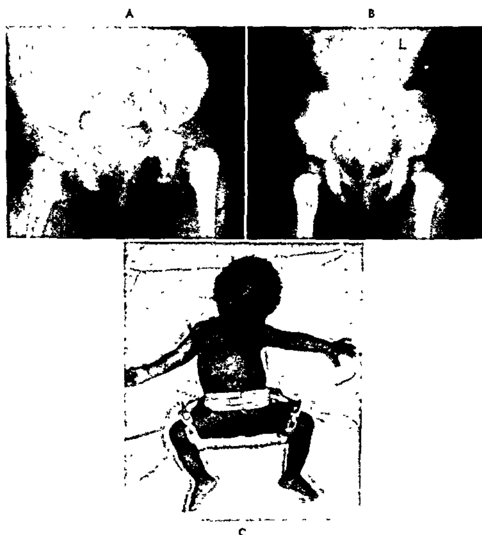


FIGURE 283. Congenital subluxation in 4 months old infant (A). Same patient eleven months later, following treatment resulting in excellent hip stability (B) Carrothers-Frieberg splint (C). Abduction can be easily controlled with this splint

Diagnosis. The characteristic diagnosis features of these infants have been well reviewed by many writers, foremost among them being Hart (1942, 1948). There are no symptoms in the infant, but certain signs can be noted.

lum varies a good deal, but the surgeon must remember that it is the *roentgenogram and not the calendar* that must be the yardstick for the length of time the head must be retained in its reduced position. A large majority of these infants require constant splint-wearing for more than 12 months and in some instances more than twice as long before the roentgenogram gives evidence of a satisfactory superior lip. If the infant's subluxation is recognized early and treatment is persisted in, statistics show that excellent results will be obtained in over 90 per cent of these hips.

Congenital Dislocation of the Hip

This condition, either a unilateral or bilateral dislocation, is often seen in the United States and it is estimated that 85 per cent of cases occur in girls. Dupuytren, in 1826, gave a classic description of the pathologic anatomy, and Paci, in 1888, described reduction of the dislocation, which up to that time had been considered incurable. Lorenz popularized the so-called "bloodless reduction," i.e., reduction by closed manipulation.

Although the displacement of the dislocation is usually upward, it very early assumes one of two positions: *anterior,* in which the head lies anterior to the acetabulum and near the origin of the tensor fascia femoris, or *posterior,* which is the more common type, with the head displaced upward and backward in the region of the dorsum of the ilium.

Etiology. A number of theories attempt to explain the origin of the dislocation. The fact that the large majority of cases are found in females lends some support to the theory that it is due to the increased width of the female pelvis, and that the hips in their normally adducted attitude *in utero* are therefore more easily dislocated. Another theory is that an injury previous to or at birth may produce the dislocation. A theory advanced by Chapple (1950) is that a relaxing hormone substance present in the female acts as a factor in softening the bones and may account for the preponderance of females having the dislocation occur *in utero.* However, it would seem that it often results from a developmental defect in the fetus, producing imperfect formation of the acetabulum *in utero* (genetic theory), although malposition *in utero* must sometimes be a factor (mechanical theory). It is difficult to explain all cases on one etiologic basis.

Often other congenital defects are noted in these cases, one of the most common being a spina bifida occulta. A hereditary factor in about

appearance of the osseous center for the femoral head indicative of delayed development is the rule.

In the so-called "acetabulum index" in infancy it is important to note the degrees in the normal and abnormal hip at different stages of their development. Probably, there is a wide normal variation, but it is helpful if the subluxation is unilateral, for then the opposite hip can serve as a control. While one expects the upper femoral nucleus in the normal hip to be visible in the first 3 months of life, it does not ordinarily appear so early in the dysplastic hip. The upper femoral epiphysis in the normal hip, however, has been known to appear as early as 2 months and as late as 8 months of postnatal life, although this is very unusual. The Hilgenreiner chart is of some help but not particularly applicable to the subluxations found in the newborn infant. In the first 3 months after birth one should be very suspicious of a subluxation if the acetabular index measures more than 35 degrees, while at 6 months of life, it should not be more than 25 degrees. It is always wise to carefully observe infants 6 to 12 months of age that show an acetabular index of more than 25 degrees (see p. 455).

Later, because of the instability of the hip, the limp, the slight shortening of the limb, and the increased susceptibility to fatigue, subluxation of the hip will not clinically be difficult to diagnose, but these hips often give very little trouble until adult life, when the incongruity of the joint surfaces gives rise to pain and limitation of motion. It is because of the late osteoarthritic changes in the adult that it is so important to recognize and properly treat these cases in infancy.

Treatment. The principle enunciated by Putti (1929) is still a sound one; the use of gradual abduction and holding the limbs in this position will permit nature to construct an adequate roof over the head of the reduced hip. The Frijka splint and various types of metal abduction splints have been used, but the simple splint devised by Carrothers and modified by Freiberg some years ago is most satisfactory. This is shown in Figure 283C and has the advantage of allowing full right-angle abduction in external rotation to be gradually accomplished. It can be enlarged and lengthened as the child grows and the degree of abduction can easily be controlled by tightening the side leather straps. Roentgenograms with the splint in place show the position of the femoral head, which should gradually be placed deep into the shallow socket and retained against the floor of the acetabulum. Relief of the stresses and strains of pressure against the limbus will permit a secure hip to develop. The time necessary to reconstruct the acetabu-

smaller than that of the unaffected hip, and after a period of walking the surface of the head becomes flattened or somewhat conical or acorn-shaped (Fig. 285). The whole femur may appear somewhat underdeveloped and, due to the shortening of the lower extremity, a curvature of the spine may develop in unilateral cases.

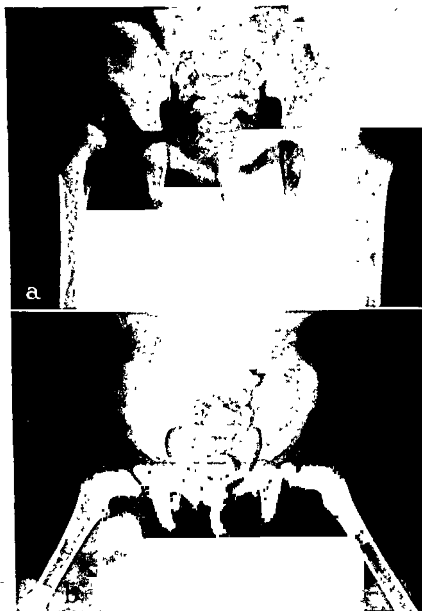


FIGURE 286. Bilateral dislocation of hips (*a*). Note upward riding of the femoral heads with wide separation of the femora. Reduction of the hips (*b*), but with insecure acetabuli.

The changes in the bony configuration of the joint are more evident in the bilateral dislocation (Fig. 286). In these the lumbar lordosis is exaggerated and the sacrum is forced forward and downward, so that

13 per cent of the cases can also be demonstrated, and undoubtedly certain races are more frequently affected than others. Among the Japanese, Chinese and Negroes, congenital dislocation is very rarely observed, whereas in Italy and France it is quite commonly found.

Pathology. In congenital dislocation of the hip one is apt to center attention upon the bony anomalies of the joint, whereas the ligaments, muscles, nerves and blood vessels undergo marked accommodative changes and are many times the more difficult portion of the deformity to treat.

Bony changes. These vary definitely with the age of the patient and with the stress and strain of weight bearing. The acetabulum is shallow, presenting an oblique and sloping roof. In early life the acetabulum in these cases is covered with normal hyaline cartilage and the ligamentum teres is present, but in the older cases the joint is covered with fibrous and fatty tissue, making it hard to recognize the joint cartilage. The ligamentum teres becomes frayed, elongated, flattened and often not distinguishable, or remains as a ribbon-like nubbin less than an inch in length. In the older cases, sometimes a secondary acetabulum above the original is formed, which is characterized by a false depression in which the head rests on the dorsum of the ilium. The femur is smaller than normal and the neck is usually shorter, with an increase in the anterior torsion of the neck. The epiphyseal center of the head is



FIGURE 285. Unilateral congenital dislocation of the hip

fancy and childhood; only in later life does the dislocated hip become painful.

The unilateral case presents a limp or lurch toward the affected side at each step. This characteristic limp is exaggerated in bilateral cases, so that the children assume the so-called "sailor waddle" as well as present a severe lordosis. The painless waddling gait with the thighs widely separated, the heads of the femora high on the dorsum of the ilia, and an extreme lumbar lordosis present the characteristic, never-to-be-forgotten picture of the bilateral case. In the unilateral dislocation the patient presents an obvious shortening of the affected extremity, which is usually rotated outward on weight bearing. When the weight is borne on the dislocated side, the pelvis tilts down on the

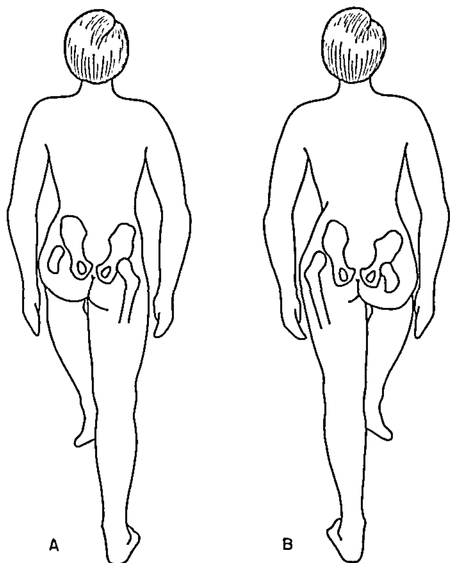


FIGURE 287. Trendelenburg sign. *A*, negative; *B*, positive.

in the older cases the transverse diameter of the pelvis is increased and the anteroposterior diameter appears decreased. In a surprisingly large number of cases other congenital anomalies, such as a lack of fusion of the laminae of the fifth lumbar vertebra or upper segment of the sacrum, will be noted, and a few cases may also have congenital clubfeet, harelip or cleft palate.

Soft tissue changes. The *capsule* which covers the head of the femur becomes elongated and thickened as the head gradually assumes its upward and backward position. It is constricted in the middle and assumes the characteristic "hourglass" shape. With weight bearing the capsule acts as a supporting ligament for the head of the femur and becomes particularly hypertrophied over the upper portion of the head of the bone. The well-known hourglass contraction is a common obstacle to reduction and is more severe in those cases subjected to repeated and unsuccessful attempts at closed reduction. Sometimes a narrow slitlike communication is found at the isthmus of the hourglass contraction or at times this is completely closed, the capsule forming two distinct sacs, one about the head of the femur and the other, rather ill-defined, in the region of the original acetabulum. The *ligamentum teres* undergoes definite changes, becoming attenuated and ribbon-like with the increase in elongation of the capsule; in many of the cases operated upon in childhood it has been found absent.

In the *muscle tissue,* it is to be noted that the pelvic-trochanteric group of muscles have changed their direction and certain groups are lengthened, whereas others are shortened. The long muscles running from the pelvis to the femur, as well as the abductor group of muscles, are shortened, whereas the external rotators and iliopsoas are slightly lengthened. These muscles, the capsule and the ligaments present a very real barrier to reduction. The degree of muscle contraction about the hip depends in large part upon the age of the patient, becoming greater in older patients; however, cases are encountered occasionally, even under 3 years of age, which are very resistant to reduction.

Clinical Picture. These children commonly do not begin to walk until around 14 to 18 months because of difficulty of balance. In many instances the mothers first make the diagnosis, or at least call the physician's attention to the fact that one leg is shorter than the other, or that one limb cannot be abducted as well as the other, or that the folds on the two thighs are different. The diagnosis often is not made before weight bearing because the hip joints are not routinely examined as are the heart, throat and lungs. The affection is a painless one in in-

rather difficult, but roentgenograms should be taken in all cases.

In the unilateral dislocation, when the child is lying on his back with the knees flexed it will be noted that the knee level on the affected side is on a lower plane than on the sound side, the so-called *Allis sign* (Fig. 289).



FIGURE 289. Allis sign in patient with congenital dislocation of the hip. With the hips flexed the knee level on the affected side is lower than on the normal side.

The above description refers to the usual or posterior dislocation, but occasionally *anterior dislocation* may be found. In these cases the shortening as well as the limp is less because the head of the femur is located under the muscles attached to the anterior superior spine. This gives a greater stability on weight bearing and therefore less limp. In the bilateral anterior dislocation the lumbar lordosis is not increased; in fact, the back is often strikingly flat.

Roentgenographic Findings. Because we rarely have pathologic material to demonstrate anatomic facts regarding congenital dislocation of the hip, we have learned to depend in large part upon our clinical examination and upon the roentgenograms. The usual roentgenogram is an anteroposterior or flat plate. The dislocation can be diagnosed but it is not possible to tell accurately the depth of the acetabulum or the degree of torsion with only a single flat plate. Stereoscopic films

opposite side because the leverage of the glutal muscles is not adequate to support the body when working at such a mechanical disadvantage. This so-called Trendelenburg sign (Fig. 287) is characteristic but not pathognomonic of congenital dislocation of the hip. The degree of telescoping which the hip presents can be easily demonstrated manually (Fig. 288) when examining the patient. This degree of laxity

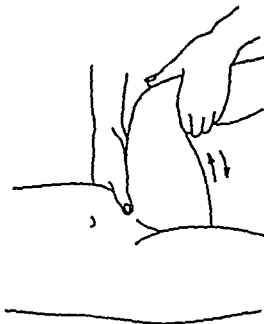


FIGURE 288 Method of eliciting "telescoping" in congenital dislocation of the hip

about the hip is an important prognostic sign, and the hip should be tested with this in mind

The range of abduction is restricted, and in the older cases flexion and adduction contractures will limit full extension and abduction. The amount of shortening in the unilateral case should always be determined by measurement; in the bilateral case the limbs are equal or nearly so. Due to the mechanical instability produced by the dislocation, the child tires easily after exertion, although he complains very rarely of actual pain. This fatigue is more marked in the bilateral than in the unilateral case.

The head of the femur can normally be felt at the intersection of the femoral artery and Poupart's ligament (see Fig. 244), and if the head is not in its normal position, we are dealing with a dislocation, congenital or acquired, of the head of the femur. This may arise from injury, disease or some type of congenital anomaly involving the upper extremity of the femur. In very young infants, the examination may be

ordinary precautions are taken, but again it must be stressed that it is never done with the child awake. Any struggling of the patient may do untold damage to the surrounding soft tissues.



FIGURE 290. Arthrography. Diodrast shows hourglass constriction of the capsule in a 17-month-old infant with congenital dislocation of the hip. Note the outline of the cartilaginous head of the femur and the small epiphyseal center above the shallow acetabulum.

Acetabular Index. The so-called "acetabular index" (Fig. 291) has been employed in determining the slope of the superior rim of the actabulum. Kleinberg and Lieberman (1936) have pointed out that an acetabular index of 30 degrees indicates an unstable socket. The acetabular index is the angle formed between the roof of the acetabulum and a horizontal line passing through the triradiate cartilage. This normally averages 20 degrees in children about 2 years of age and 27.5 degrees in newborn infants. In the unilateral dislocation, the femur and pelvis are both smaller and more undeveloped than on the opposite side and the epiphysis of the head of the femur, which appears during the first year, is above its normal position.

The widening of the joint space, which indicates that the femoral head is in an unstable position, should also be noted. This condition

give more information; a set of two plates made with the hips in (1) the neutral position and (2) internal rotation gives a clearer idea of the torsion of the neck.

A careful study of roentgenograms taken in different positions will reveal facts of great prognostic aid for they will give a great deal of information about the appearance of the head and neck. If they appear symmetrically formed the prognosis following either a closed or an open reduction is much better than if the head is misshapen. Sometimes the head is so deformed that even following adequate reduction, there will be an incongruity of joint surfaces sufficient to give trouble later. No reconstruction of the head should ever be done in children.

Arthrography. In addition to roentgenograms, the employment of arthrography may give additional information. This is done as follows:

The child must always be anesthetized before attempting arthrography. The best approach is the anterior one, the skin being prepared and draped in the usual manner. A No. 20 needle with a stylet is used. The femoral artery is palpated just below Poupart's ligament; the needle is then inserted lateral to this and in a slightly cephalad direction downward, against the bone, and the surgeon can identify whether the needle is touching the femur or the acetabular rim by gently rotating the femur. Then, after withdrawing the stylet, 2 or 3 cc. of normal saline are injected, and if the needle is in its proper position inside the joint and in contact with the femoral head or neck it is possible to withdraw the injected fluid After withdrawing the saline, 3 to 5 cc. of a 17.5 per cent Diodrast is injected and roentgenograms are taken (Fig. 290). The excess Diodrast is then withdrawn and additional films taken. Heublein feels that these additional films are particularly valuable as they afford further information regarding the status of the hip joint and the cartilaginous femoral head. The Diodrast is absorbed rather rapidly both from the joint and from the surrounding soft tissues. A film made 20 minutes after injection reveals no significant opaque residue.

Closed or open reduction may follow the injection of Diodrast solution. No evidence of irritation of the synovial lining by the contrast medium has been observed.

The film from arthrography will show the outline of the cartilaginous cap (Erik, 1939), and in cases in which persistent and unsuccessful attempts at closed reduction have been made, an hourglass constriction and evidence of capsular redundancy will frequently be disclosed (Fig. 290). Arthrography is thought to be a useful and harmless procedure if

of bilateral and 75 per cent of unilateral cases have been reported to have resulted in almost normal function (Krida *et al.*, 1936). In the older cases the results are not so satisfactory and they decrease in direct proportion to the age when treatment is begun.

Treatment. It should be explained to the parents that a long period of careful supervision will be necessary to treat any case of congenital dislocation of the hip. The acetabulum is usually shallow so that some method must be followed that will give security and stability to the head of the femur.

In the greater percentage of children under 3 years of age, reduction of the head from its dislocated position into its reduced position, retaining it there for some months, is sufficient for an adequate socket to be developed.

However, in a few cases open surgery will be necessary and this should be directed towards increasing the depth of the socket. This can be achieved in two ways: (1) by an osteoplastic buttress to the superior portion of the acetabulum, or (2) by reaming out a deep socket from the thick innominate bone at the level of the site of the normal acetabulum and placing the capsular-covered head deep into this socket.

Although age is not the only factor in deciding upon the type of treatment most suitable, this criterion lends itself to a satisfactory plan of treatment.

Treatment under 3 years of age. During infancy the majority of patients with congenital dislocation of the hip can undergo treatment as follows: Gentle manipulation under general anesthesia is necessary to effect reduction. Fixation in the "frog" position is retained by brace or plaster. Repetition of this conservative treatment, if necessary, is felt to be less damaging to the development of the anatomical structures than resorting to a surgical procedure in these babies.

After a child has begun to walk but is under 3 years of age, the closed manipulative method is most satisfactory. The old Lorenz maneuver, or modifications of it, offers the basis for most of the manipulative measures now employed. This consists of a thorough but gentle stretching of the hamstrings and a tenotomy of the adductor muscles under anesthesia, after which the patient receives traction. Skin traction is satisfactory and it is most effective if the unaffected side is immobilized in a spica. Six to ten pounds of traction (Fig. 292) for a few weeks is usually effective in young children to bring the femoral head down opposite the acetabulum.

The child is then anesthetized again. The hip can now usually be

permits the head to press upon the remaining superior portion of the acetabulum and is a constant force forming a socket more shallow than it would otherwise be.



FIGURE 291. Shallow acetabulum on left indicating an unstable socket.

Differential Diagnosis. Acquired pathologic dislocation of the head of the femur may follow an epiphysitis or a disease process in infancy, but in such cases a destruction of the head of the femur and often scars about the joint show evidence of the former disease. In addition, history of an acute illness is given

Occasionally the gait may be suggestive of a rachitic coxa vara, a congenital coxa vara, Pott's disease of the lumbar region or an early progressive muscular dystrophy. However, if the history and examination of the walking child are carefully taken, it will be noted that a congenital dislocation presents so many characteristic features that it ought not to be confused with any other condition. In cases of doubt roentgenographic findings will make the diagnosis definite.

Prognosis. If the treatment is started under the age of 3 years, before many secondary changes have made themselves manifest, a great majority if the cases can be successfully reduced and kept reduced by *nonoperative measures* When treated under 3 years of age, 65 per cent

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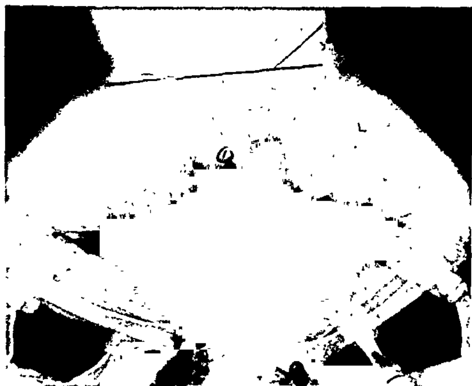


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reduced with a definite click. The position is checked by roentgenograms while the patient is asleep and before applying plaster. If the roentgenograms show satisfactory reduction (see Fig. 286b), the limb is kept in the frog position and a plaster spica applied (Fig. 293). A modification described by Krida (1928) keeps the hip in the *frog*

DIRECTION OF TRACTION

FIGURE 292. Soft tissue traction used before closed or open operation *Left*, before traction; *right*, effect of traction.

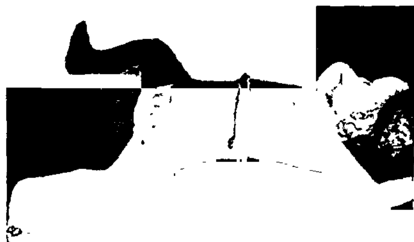


FIGURE 293 The "frog" position.

position for 2 weeks; then, whenever there is an unusual amount of anteversion present, the head will be found to sink more deeply into the socket if *internal rotation* is applied (Fig. 294). Two weeks later the plaster is changed and the limb placed in internal rotation and abduction and held for approximately 6 weeks, at which time a closed



FIGURE 294. Reduced hip in internal rotation when anteversion of the neck is marked. This places the head of the femur deeply within the acetabulum. Subsequent treatment is supracondylar osteotomy according to the method of Krida.

manual supracondylar rotation osteotomy is done. This can usually be done manually and with ease in children under 2 years of age, but occasionally an open supracondylar osteotomy is necessary. In the closed procedure the distal fragment is rotated outward so that the patella points directly upward while the relationship of the head of the femur to the acetabulum is held unchanged. Plaster is again applied with the limb in wide abduction. This plaster is worn for 6 months before being removed. The hip is checked with roentgenograms to determine the rate of healing of the supracondylar osteotomy. Following plaster removal, muscle training and physical therapy are

instituted while weight bearing is gradually started. This gradual rehabilitation improves the tone of the already weakened muscles.

This method, or slight modifications of it, permits the child under 3 years of age with the usual congenital dislocation of the hip, whether bilateral or unilateral, to begin weight bearing without plaster within 6 to 8 months after treatment has been instituted. One must see that each plaster is snug but not too tight, and that it is properly padded to avoid pressure sores. It should be changed at any time during the course of treatment if it becomes soft and ineffective in holding the limb in the desired position.

Anteversion of femoral neck. Dunlop *et al.* (1953) have published a method for determining the true neck torsion. This is arrived at by getting posteroanterior and lateral roentgenograms of the pelvis and hip, positioning the lower extremity with great care, which permits the apparent torsion to be measured. A true angular torsion is determined, therefore, from the apparent angle of torsion and the measured inclination by the use of a trigometric formula. This method is rather complicated (Shands and Steele, 1953), but accurate, and is excellent for collecting statistical data. From a practical standpoint, if the limb is rotated inward until the head is securely seated in the socket as verified by roentgenogram, the opportunity for its redislocation is minimized; for this reason inward rotation during the second stage of the manipulative method described previously has been found very helpful. If increased torsion is not present, the frog position is maintained for 3 to 6 months and then the limb gradually brought into less abduction and external rotation with each succeeding plaster. Immobilization in the form of a night splint is continued for the next few months, followed by gradual return to normal activity approximately a year after beginning treatment. It is rare that open reduction is necessary under the age of 3. If, however, several efforts at closed reduction have been unsuccessful, there would appear to be a mechanical soft tissue obstruction preventing complete hip reduction and open operation would then be advisable.

Treatment between 3 and 8 years of age. This has been a problem for years, as in this period it is hard to achieve reduction and to restore form and function to the dislocated hip. Sometimes a closed manipulative reduction following the method of Lorenz previously described has resulted in a satisfactory hip in children 4 and 5 years old, but this is most unusual. The force necessary for manipulation has frequently resulted in inadequate reduction or developmental changes in the

femoral head, giving rise to a stiff hip. Therefore, the choice of treatment in congenital dislocation of the hip must be decided upon only after a number of factors have been considered. The age of the patient is one of the most important, although the amount of soft tissue relaxation as shown by telescoping and the roentgenographic appearance of the osseous elements comprising the hip joint are all basic considerations.

The author's experience with the use of the shelf operation at this young age has been discouraging, for under 8 years of age the buttress type of operation is likely to be unsatisfactory as shown by long follow-ups. Since 1930, the author has used a two-stage procedure which has utilized the synovial-lined, hour-glass capsule about the head of the femur and has been called the Capsular Arthroplasty Operation. The author's best results have been obtained in patients under the age of 8 and with the unilateral cases. The operation is predicated upon the fact that the gliding mechanism of the femoral head and its encircling synovial membrane can be transplanted into the reconstructed deep acetabulum which is at the same level as the normal acetabulum.

In the safe reduction of any congenital hip dislocation, adequate relaxation of the soft tissues about the joint must be present or must be obtained preliminary to open operation. In the method to be described a preliminary closed first stage is necessary. This consists of a subcutaneous adductor tenotomy and the stretching of the hamstrings while the patient is under anesthesia, followed by the application of skin or skeletal traction to the dislocated side (see Fig. 292). The sound side is routinely immobilized in a long plaster spica. This *first stage* must be continued until the femoral head is pulled down opposite the level of the deficient acetabulum. Usually this requires 2 or 3 weeks, although here again the surgeon must be guided by the effectiveness of the traction as shown by roentgenograms. Then and only then should the *second stage* or open operation be done. Very rarely can one demonstrate by push and pull roentgenograms sufficient relaxation preoperatively, but in the few cases in which this can be done the first stage may be omitted.

The second stage of the procedure, the open operation, differs fundamentally from the various buttressing or shelf types of operation. In the capsular arthroplasty security is obtained by central replacement of the head into its exact anatomical position rather than by building a ledge or shelf laterally and frequently posteriorly over the femoral head. In this second stage great care is taken to remove all the articular cartilage

before reconstructing the acetabulum into a cup-shaped rather than a saucer-shaped cavity and before placing the head and its covering of capsule into the newly made socket. It is believed that central placing of the head is a very important factor in restoring motion as well as in assuring stability, but *under no circumstances must the femoral head be remodeled by surgery.*

At the time of the second stage of the operation, if anterior torsion of the neck needs correction, the head should be placed deeply into the newly made socket by rotating the entire limb inward for deep seating (Fig. 295). Two weeks later this hip then must undergo a supra-

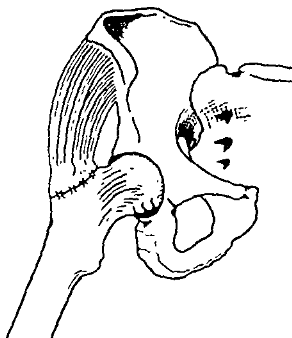


FIGURE 295. Capsular-covered head of femur well placed in reconstructed acetabulum.

condylar osteotomy; the distal fragment is then derotated while the proximal fragment is held in the same position by a temporary Steinmann pin through the greater trochanteric region.

One must assume that the transplanted capsule becomes firmly adherent to the floor of the acetabulum and that the synovial cells undergo a metaplasia, transforming them into cartilage-like cells. Certainly, this transition which occurs in the transplanted capsular structures must be very rapid, for active motion can be started 4 or 5 weeks after the second-stage procedure. Weight bearing, however, has been routinely delayed for 3 to 6 months, depending upon the degree of active non-weight movement in bed.

The variations that can be encountered under the general term of congenital dislocation of the hip are surprising and they do not all follow a set pattern of clinical and roentgenographic features. The differences from the normal configuration of the femoral head can give rise to varying degrees of postoperative function and while we can construct a satisfactory socket from a deficient acetabulum which results in a very satisfactory range of motion, one must never attempt to surgically reconstruct a deformed or misshapen femoral head in a child.

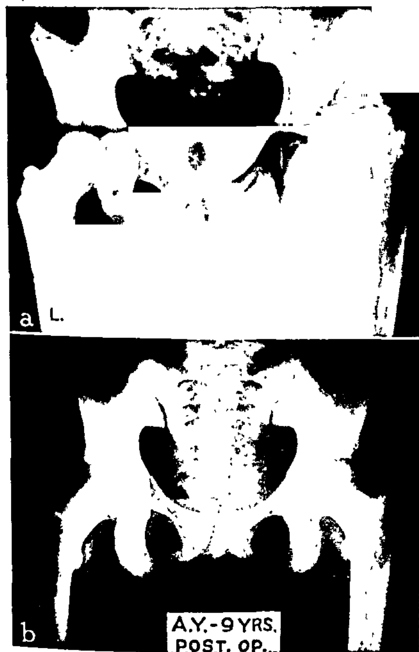


FIGURE 296. Congenitally dislocated hip in 6-year-old child. Before treatment (*a*). Nine years after two-stage arthroplasty operation (*b*).

Such a procedure will always result in growth changes and severe limitation in function. Therefore, a careful selection of patients based on the preoperative clinical and roentgenographic features, plus meticulous technic in the steps of this operation and proper long-continued postoperative care have produced excellent results (Figs. 296 and 297). *The operation is not suited to subluxation of the hip but is for the congenital dislocated hip* (Colonna, 1953). The technic of the operation is described in more detail in many printed articles, but a recapitulation of the postoperative care, a very important phase of the rehabilitation, follows.



FIGURE 297. Bilateral congenital dislocation of the hip. *Left*, before operation; *right*, 9 years following operation.

Postoperative care. After 4 weeks remove spica, preserve posterior splint. Begin balanced suspension and active abduction motion. Keep sandbag between legs to avoid *adduction*. After one month patient should alternately sit up or lie on stomach daily. Second month suspension should be discontinued but sandbag should be kept between legs. Activity started in bed and therapeutic pool but no standing or kneeling. No weight bearing under 3 months, and then only for short intervals in walker. Watch for muscle spasm and tightening up of motion at beginning of weight bearing. If joint motion becomes less, stop standing and put child to bed with skin traction at once. At the end of 6 months — cases having been carefully chosen — the child should walk without a limp, enjoy normal activities and present an almost normal range of motion. Try to keep patient under observation indefinitely and check with roentgenograms every 6 to 12 months. If anteversion is marked, it must be corrected as described in text (p. 460).

Treatment from 8 to 18 years of age. This period is the ideal age

period in which a buttress type of procedure, or so-called shelf operation, should be used (Fig. 298). There are many types described, although the author prefers the Gill type (Gill, 1935). This age period precludes any successful attempt to get an anatomically central reduction, but these buttress types of operation do assure stability of the hip. This is, of course, necessary and extremely helpful to the patient, but in the technic of the operation great care must be taken not only to



FIGURE 298. Result of a shelf operation to deepen the defective acetabulum with a bony buttress.

bring the head down to or as nearly opposite the original acetabulum as possible, but to correct the disfiguring and fatiguing lurch. To do this the head should be brought forward in relation to the sagittal plane of the body. This is important and is often neglected. A thorough preliminary stretching of the shortened and contracted soft tissues including muscles, fascia, ligaments, blood vessels and nerves should be done slowly but effectively.

Shelf operations are not only helpful in most cases of old dislocations, but also very useful in giving more security and lessening the strain to the hip structures and back. In subluxation of the hip this procedure

is ideal. The long-standing shortening of these structures, however, makes it dangerous and unsafe to attempt anatomical reduction of the hip in the adult patient. When relaxation is marked in the unilateral case, hip fusion may be desirable.

Treatment in the adult. Those patients beyond the age of 18 years frequently have adjusted themselves to the added stresses and strains of a dislocated hip, but find that activity becomes increasingly difficult and painful as they get older. In certain instances arthritic changes begin to add to their troubles and some type of surgery may become necessary. Surprisingly enough, many of these patients are well adjusted to a life of restricted but fruitful activity and simple correction of the shortening by a high shoe, if the condition is unilateral, gives a great deal of relief. Limiting their physical activities by rest at intervals during the day may allow them to carry on remarkably well. Baking and massage to tone up their tired and strained hip and back muscles or swimming, bicycling, horse-back riding, rowing, and so forth are all activities from which they may obtain a great deal of benefit. In bilateral cases the lumbosacral joint carries an extra load of stress and strain and a back brace may at times be helpful. Certainly, conservatism should be of the first consideration in these older patients and surgery contemplated only as a last resort.

In some instances, a shelf operation may be selected or in cases of bilateral congenital dislocation with pain, a bilateral Lorenz operation or a Schanz osteotomy may give more stability and lessen the arthritic pain that so frequently develops in older patients. No effort should be made to attempt to achieve an anatomical reduction because of the dangers adherent in stretching long-contracted soft tissue. A vigorous surgical approach to this problem in the adult may lead to paralysis, gangrene or other dire results and may leave the patient much worse than before surgery.

Congenital Coxa Vara (Cervical Coxa Vara)

Congenital coxa vara (cervical coxa vara) was first described by Mandel in 1896. It may be the only congenital anomaly present or it may occur in association with other congenital deformities.

Clinical Picture. The condition is usually observed in early childhood although it may not be recognized until later in life. It is usually bilateral. The patient presents an awkward gait and tires easily. On examination of the hip restriction to abduction and internal rotation is found, and the greater trochanter is noted to be above Nélaton's line.

The actual amount of discomfort present will depend upon the degree of coxa vara. Pain due to the excessive strain placed upon the muscles about the hip may sometimes be severe or may be very slight, but there is always some atrophy of the muscles.

The roentgenographic findings (Fig. 299) are characteristic and show a coxa vara deformity which is usually rather severe, and the epiphyseal line, instead of being horizontal or oblique, is almost vertical so that the stress and strain at this weak point is great. The deformity is of the entire head and neck, and in the older cases may give rise to severe mechanical disability.



FIGURE 299. Bilateral congenital coxa vara. *Insert* shows the extreme lordosis also characteristic of congenital dislocation of rachitic coxa vara.

Differential Diagnosis. If the condition is unilateral, it may be clinically confused with slipping of the upper femoral epiphysis or fracture of the femoral neck. If bilateral, the gait and limp are quite suggestive of congenital dislocation. Pain is not usually a prominént feature, but if acute, it may resemble some type of infection such as tuberculosis. In the tuberculous hip, however, motion at the joint is limited in every direction by muscle spasm; this, of course, is not true in cervical coxa vara.

Treatment. As the mechanical deformity is the underlying cause of the symptoms, the primary object is to restore the mechanics, and usually this is most satisfactorily done by a wedge osteotomy at the level of the lesser trochanter. The limb is then widely abducted and a plaster spica applied for 8 to 10 weeks, or until bony union has occurred. On removal of the plaster, physical therapy with active and passive exercises is employed. In the adult patient or those with very severe deformity, the Dickson type of geometric operation may produce a rather useful and stable hip, although restricted in motion (see Fig. 273).

Otto Pelvis (Intrapelvic Protrusion of the Acetabulum)

Otto pelvis (intrapelvic protrusion of the acetabulum) was first described by Otto in 1824 as protrusio acetabuli, and he attributed it to a form of gout. Verral in 1929 called this *arthrokatadysis.* The condition is characterized by localized destruction or softening of the acetabulum.

Etiology. The etiology is unknown, but it is thought to be the end result of an inflammatory process producing a newly formed acetabular floor and a permanent dome-shaped intrapelvic protrusion. Mercer (1948) has described two groups: (1) a juvenile osteo-asthenic protrusion group found in girls at the age of puberty and without any traumatic,



FIGURE 300. Intrapelvic protrusion of the acetabulum (Otto pelvis). Note that the acetabulum appears to be pushed inward by the head of the femur.

infectious or arthritic changes; and (2) the rheumatic group, associated with a subacute infection.

The majority of the cases are recognized in middle-aged women, both hips being affected in about one-third of the patients. Gradual pain and stiffness are felt in the hip with severe limitation of abduction and *rotation; the discomfort and pain is definitely increased by weight* bearing. The diagnosis is made by roentgen examination (Fig. 300).

Treatment. This largely consists of limiting the physical activity, with heat and massage to the affected hip muscles. In the advanced cases, recumbency and traction to the affected limb often give relief for a time from pain, but if the pain becomes severe an arthroplasty of the joint may be indicated.

The Pelvic Ring

APPLIED ANATOMY

The pelvic ring is composed of the two innominate bones and the sacrum (Fig. 301), *the sacroiliac joint being braced by strong anterior* and posterior ligaments.

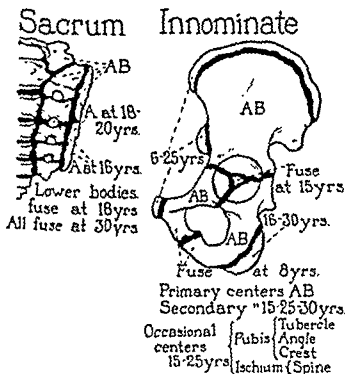


FIGURE 301. Time of appearance and fusion of the epiphyses of the pelvic ring. AB: at birth.

The pelvis is divided into a true and false pelvis by the iliopectineal line. The pelvis is of importance both because of the acquired conditions of disease and injury which affect it, and also because it plays an important part in congenital malformations, especially congenital subluxation and dislocation of the hip.

Sacroiliac Joint. The sacrum, an inverted triangle with its base upward, is firmly held by strong ligaments anteriorly and posteriorly between the innominate bones. The lumbosacral joint, due to its downward and forward inclination, is the seat of many mechanical stresses and strains (see Low Back Pain, Chapter 3). The sacroiliac joint is lined by a thin layer of articular cartilage covering the roughened articular surfaces of the ilium and sacrum. The joint possesses a very slight rocking motion which can be demonstrated by a slight backward and forward movement in the vertical plane. Ligamentous and muscular injury at this joint occur during twisting or turning motions, giving rise at times to severe pain and almost complete disability. Actual joint displacement sufficient to be demonstrated in roentgenograms can occur with only very severe injury.

DISEASES

Tuberculosis

This joint is the seat of a tuberculous lesion involving most frequently the lower half of the lateral mass of the sacrum. In comparison with tuberculosis of the hip or spine, the sacroiliac joint is rarely involved and is insidious in onset.

Clinical Picture. *Pain and limp are the outstanding features.* The pain may be locally over the sacroiliac joint or radiating down to the buttocks or thigh. It is increased by sudden jars or twists. In order to protect the joint the body is frequently deviated toward the sound side, the patient developing the so-called "sciatic scoliosis" attitude (see Fig. 113). Forward bending of the spine and straight leg raising are restricted and painful and iliac compression often aggravates the pain. A rectal examination should always be done as an abscess develops in the majority of these cases in the later stages.

Differential Diagnosis. Low back pain of lumbosacral origin may be due to acute or chronic strain, disease, fracture, new growth, protrusion of an intervertebral lumbar disk or hip joint disease, all of which may simulate sacroiliac joint disease, although a careful examination should eliminate the spine and hip condition. When it has

reached the stage of joint destruction, roentgenograms (Fig. 302) make the diagnosis easy.

Complicating abscess formation with or without sinus formation and frequent pulmonary involvement make the outlook grave in the advanced case.



FIGURE 302. Tuberculosis of left sacroiliac joint.

Treatment. Streptomycin should be routinely employed before, during and after surgery unless the patient is sensitive to the drug. Conservative treatment is of doubtful value. If surgically feasible, fusion of the joint following the Smith-Petersen technic is done as soon as the disease is identified. If an infected sinus has developed, a long course of streptomycin frequently produces healing. Fusion must be delayed until the sinuses have healed. In these severely infected cases there is a high mortality rate.

Osteomyelitis

Osteomyelitis (Fig. 303) involving either of the innominate bones or the sacrum is uncommon if we leave out of consideration the acetabular involvement in hip joint disease. The ilium, ischium or pubic

bones are involved in that order, the disease being almost always of hematogenous origin. However, direct extension from an infected pelvic viscus does occur (Fig. 304). For the pathology of osteomyelitis refer to Chapter 2.



FIGURE 303. Osteomyelitis of the pelvic ring.

An acute osteomyelitis of the ilium may produce large, subperiosteal abscesses invading both outer and inner tables of the bone, requiring not only preliminary adequate constitutional treatment by transfusions and antibiotics, but also ample incision and drainage.

In the region of the rami or the tuberosity of the ischium adequate exposure is not so easily obtained as in that of the ilium, and the surgeon, after opening the abscess and inserting a drain, may have to depend largely on the type of antibiotic most potent against the organism to effect a cure.

In cases of chronic osteomyelitis which are massive in character, involving large areas of the innominate bone and giving rise to uncontrolled toxicity, a hemipelvectomy has been necessary as a life-saving procedure. While the mortality rate in hemipelvectomy has been

markedly lowered in recent years, this is still a formidable and disfiguring type of operation (see Bone Tumors, Chapter 16).



FIGURE 304. Circulatory obstruction in acute osteomyelitis of right side of pelvis (infrared photograph).

INJURIES

Sacroiliac Joint Strains

Strains at this joint are not frequent. Many of the so-called "sacroiliac *strains*" can be proved to be lumbosacral in origin. Quick twisting movements with the body caught off guard may produce minute ligamentous or muscular fiber tears giving rise to a great deal of local pain; frequently the trunk is deviated to one side by the inequality of muscle pull caused by spasm (see Fig 113).

Clinical Picture. Generally all motions of the lumbar spine are painful and restricted, especially extension. Straight leg raising on the affected side is limited, in fact it may be limited on both sides, with the pain referred to the involved sacroiliac joints. In these acute strains, pain is localized over this joint posteriorly. Anteriorly, palpation through the abdominal wall over the sacroiliac joint causes pain (*Baer's sign*). Compression of iliac crests may aggravate the pain. Motor and sensory changes are rare.

Although simple, acute sacroiliac joint strains do occur, one must suspect the presence of disease in the sacroiliac joints if the disability becomes chronic; even then the signs and symptoms may be quite similar

to strain. However, with disease the roentgenographic examination will show some joint involvement, and if a rectal examination is done, a fluctuating mass may be occasionally detected over the anterior surface of the joint, indicative of abscess.

Differential Diagnosis. The list of the body toward one side or the other noted in both sacroiliac strain and sacroiliac disease is not pathognomonic of these affections, as this same temporary scoliosis may be found in lumbosacral strain, in protrusions or ruptures of the intervertebral disks between the fourth lumbar, fifth lumbar and first sacral vertebrae or in malignancies of this area. In patients suffering from repeated attacks of either sacroiliac or lumbosacral strain, roentgenograms may reveal certain congenital anomalies, particularly lack of fusion of the laminae of the fifth lumbar or upper sacral vertebra, asymmetrical facets, enlargement of the fifth transverse process, which will sometimes abut against the wing of the sacrum (the so-called sacralization), and which may become completely or incompletely fused to the sacrum, as well as other defects in the development of the neural arch; sometimes an actual displacement of the fifth lumbar vertebra on the sacrum will be found, the so-called spondylolisthesis (see Low Back Pain, Chapter 3, p. 154).

Treatment. Strapping, by adhesive encircling the pelvis, or supporting the back by extending adhesive from several inches in front of the anterior superior spine around the back to the opposite side, is indicated. In the acute stage pain may be so severe that weight bearing is impossible and the patient feels completely disabled. In these cases the patient will recover from his acute attack more quickly if he is put to bed and weight bearing completely denied him. He should rest on a firm, well-supported mattress and receive physical therapy, consisting of daily diathermy, dry heat such as a lamp or an electric pad, and gentle massage to the muscles of the back and buttocks. Sometimes traction to one or both lower extremities renders these patients more comfortable when in bed. Later a properly fitting back support is needed and the patients are gradually permitted to resume weight bearing. If these acute strains do not respond to this form of conservative treatment, or if an arthritis of the sacroiliac joint can be demonstrated by roentgenogram, a surgical fusion to eradicate all movement completely may have to be done.

Separation of the symphysis pubis alone is rarely seen and can be treated by suspending the pelvis in a canvas hammock. If the separation is marked, a careful study of the sacroiliac joints will probably

also show injury to these joints, and reduction under anesthesia may become necessary.

FRACTURES

Crushing injuries which compress the pelvis anteroposteriorly or laterally, as well as injuries resulting from falls from a great height, will produce fractures of the bony framework of the pelvic ring.

Fracture of the Pelvis

Fracture of the pelvis includes fractures to the innominate bone, sacrum and coccyx, as well as into the acetabulum. The commonest causes are crushing injuries or falls from a great height. Frequently they occur without much displacement at the site of the fracture, although the accompanying soft tissue damage may give rise to very serious complications.

In any severe pelvic injury associated shock of considerable degree may occur; retroperitoneal hemorrhage may be followed by intestinal paralysis and distention. If any complication contraindicates simple circular strapping, the pelvis may be suspended by means of a heavy canvas hammock (see page 765) a few inches off the bed, which permits sufficient lateral compression to reduce and immobilize the fracture at the same time the soft tissue damage is being treated.

Very rarely is it necessary to perform an open operation to reduce the fracture fragments. Spicules of bone may perforate the bladder, urethra or other adjacent structures, however, and make an open operation necessary.

Fracture of the Wing of the Ilium

Fracture of the wing of the ilium is usually treated by several encircling bands of 2 or 3 inch adhesive strapping or Ace bandage applied about the pelvis to immobilize it, and by the use of the pelvic suspension hammock.

Fractures of a Single Ramus of the Pubis or Ischium

These fractures (Fig. 305) are not usually serious and rarely require more than a few weeks' rest in bed in a pelvic sling. A light pelvic canvas back support makes the patient more comfortable when weight bearing is assumed. When a double fracture of the pubis is on the same side, it is usually produced by some lateral compression

force. The bones usually heal without difficulty, but a 6 to 8 weeks period of recumbency is necessary.



FIGURE 305. Fracture of the ramus.

Avulsion Fractures

Avulsion fractures may be produced by sudden muscular contractions tearing off a small chip of bone from the origin of the muscle. The most frequent are (1) avulsion of the anterior inferior spine, (2) avulsion of the anterior superior spine and (3) avulsion of the tuberosity of the ischium. Recumbency for a few weeks with the hip and knee flexed is indicated. An open operation and complete reduction of the fragment are not usually essential to the recovery of good function

Fracture of the Sacrum or Coccyx

Isolated fractures of the sacrum are rare, and usually consist of a fissure fracture without displacement, these fractures heal quickly.

Fracture of the coccyx may occur when the patient falls suddenly, landing in a sitting position The injury is a rather painful one. The fracture is treated by strapping the buttocks closely together with adhesive strapping and protecting the bone against reinjury. Usually the patient is free from pain in a few weeks. However, a rectal examination should always be made.

Should the rectal examination show displacement of the coccyx, an air cushion is useful when the patient is convalescing.

An emotional element apparently enters into some cases which have a prolonged convalescence from coccygeal injury, and they do not, as a rule, do well with excision of the coccyx. Surgical removal of the coccyx is rarely necessary, but if it is done, a transverse, rather than a longitudinal, incision will more easily avoid rectal contamination.

In *severe contusion at the sacrococcygeal joint* a *bursitis* may develop, which will closely simulate the symptoms found in a fracture of the coccyx. If the roentgenogram is negative for bone injury, radiation to this area will often relieve the local pain.

Sacroiliac Joint Subluxation and Fracture-dislocation

Displacement of the actual joint surfaces of this joint are not common and are the result of severe injury. Roentgenograms, however, may disclose a *subluxation* and, if found, every effort should be made to manipulate the joint into position. Usually it is more satisfactory to give the patient an anesthetic and effect the reduction by rotating the ilium forward; then the back is supported by firm adhesive strapping.

In the *fracture-dislocation* type of case, the patient will give a history of violent trauma. This condition has been encountered in children who have suffered a direct blow by a car and have been dragged for some yards before being rescued. In this type of injury one must search for some damage to the viscera as well. In the adult it may be produced by a fall or by the pelvis being squeezed anteroposteriorly, producing not only fracture-dislocation at the sacroiliac joint, but also a displacement at the symphysis pubis (Fig. 306).

If the soft tissue damage is not serious, an attempt should be made as soon as possible to reduce the upward displacement by manual traction or by heavy skin traction applied to the lower extremity; the opposite side should be immobilized in a plaster spica. To rule out bladder injuries, the patient should always be catheterized at once. A clear urine means no injury, but if the urine is bloody there is probably injury to the urethra. If only a small amount of bloody urine or no urine is obtained after a difficult catheterization, rupture of the bladder is most likely. If damage to the urethra or bladder is suspected, the co-operation of the urologic surgeon should be obtained as soon as possible.

Central Acetabular Fracture

A direct blow or a fall on the lateral surface of the trochanteric region may drive the head of the femur thorough the floor of the

FIGURE 306. Fracture-dislocation at the left sacroiliac joint with separation at the symphysis.



FIGURE 307. Intrapelvic or central dislocation at the head of the femur. (Callander, *Surgical Anatomy*.)

acetabulum, producing this type of fracture. Comminution of the acetabular floor often results, with occasionally some injury to the intrapelvic structures. Accompanying fractures of the pelvic ring may also occur with the acetabular fracture and these should be sought.

There is severe pain and disability, with inability to bear weight and with pain on any movement of the hip joint. A flattening of the flank can be noted and there is shortening of the limb to a varying degree. Roentgenograms (Fig. 307) are essential to establish a diagnosis.

Direct skeletal traction laterally through the greater trochanteric region for 8 to 10 weeks may be employed. If the ilium is not involved in the fracture, simple abduction of the limb while the patient is under deep anesthesia will permit the sunken femoral head to be levered out of the floor of the acetabulum. The limb should be held in a wide abduction spica 6 to 8 weeks, then weight bearing begun gradually. The hip must be protected from full weight bearing for at least 6 months.

Very heavy skin or supracondylar skeletal traction with the unaffected hip in a single spica can be tried and often is remarkably successful in gradually disengaging the head of the femur out of the acetabulum. Traction must be as heavy as can be tolerated, 30 to 40 pounds if possible, and continued for 6 to 8 weeks, then gradually lessened.

When the comminution has been extensive, *late arthritic changes* in the hip joint quite frequently develop after this type of fracture. If pain and stiffness with roentgenographic evidence of arthritic changes develop, an arthrodesis of the joint becomes necessary.

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10

The Thigh

APPLIED ANATOMY

The thigh region includes the shaft of the femur (Fig. 308), surrounded by three main groups of muscles: the extensors and flexors of the knee and the adductors of the thigh, as well as the superficial tensor fascia femoris muscle. Accompanying the muscles are the femoral vessels, nerves and fascial sheaths.

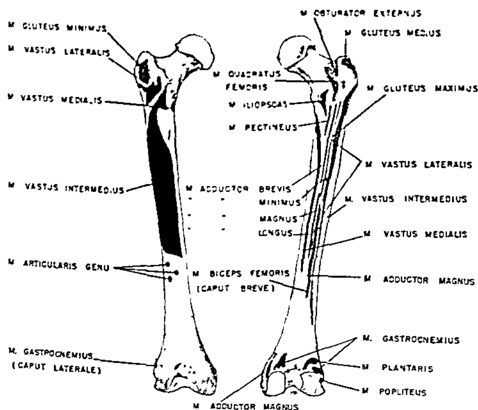


FIGURE 308. Femur with muscle attachments. Red: muscle origin. Blue: muscle insertion.

The *extensor group* of muscles is composed of the sartorius and the quadriceps group, the latter made up of vastus internus, externus, intermedius and rectus femoris. The quadriceps extensor group of muscles combine to form a common tendon which encloses the patella and is inserted as the ligamentum patellae in the lower part of the anterior tubercle of the tibia. The vasti muscles surround the entire shaft of the femur except the middle lip of the linea aspera and the two extremities of the bone. The rectus femoris is the only portion of the quadriceps muscle that arises from the pelvis. The extensor group is supplied by branches from the femoral nerve.

The *posterior femoral* (hamstring) group of muscles are flexors of the knee, and are composed of the biceps flexor cruris, semitendinosus and semimembranosus — all supplied by the great sciatic nerve. These hamstring muscles act as flexors of the leg upon the thigh, and extensors of the thigh upon the pelvis.

The *adductor group* of muscles is composed of the adductor brevis, longus, magnus and the small gracilis muscle, lying between the flexor and extensor group on the inner side of the thigh. In addition to being adductors the first two are flexors of the thigh on the pelvis, and when the thigh is rotated inward they also become powerful outward rotators. These muscles are supplied chiefly by the obturator nerve.

If the thigh is flexed and rotated outward, the sartorius muscle can be seen crossing it obliquely, and its action is flexion of the hip and outward rotation of the thigh. On the upper front border of the thigh lies an important triangle known as *Scarpa's triangle,* whose outer boundary is the sartorius muscle, its inner border, the adductor longus, and its base, *Poupart's ligament.* Entering Scarpa's triangle are the femoral vessels and nerve. This triangle is the usual site in which femoral hernias make their appearance and where psoas abscesses from the hip or lower spine occasionally gravitate down under the psoas muscle and appear as a fluctuating mass. The triangle is a favorite site for ligation of the femoral artery. The artery enters the base of Scarpa's triangle and exits through an aperture in the adductor magnus muscle, called *Hunter's canal.* This canal is formed by the adductor longus, magnus and vastus internus muscles, with the sartorius muscle lying on the roof of the canal. Passing through it are the femoral artery and vein and the long saphenous nerve.

The muscles of the thigh are covered by an investing fascia which is stronger and thicker in certain regions. This fascia lies just beneath the skin and superficial fascia; on the lateral side of the thigh it is a

thick fibrous membrane called the fascia lata. After the investing fascia of the thigh extends to the knee, surrounding the joint, it passes on to become the investing fascia of the leg. The upper portion of the fascia has inserted into it the tensor fascia femoris muscle. Sometimes there is spasm of this muscle and pain along the lateral aspect of the thigh. *Fasciotomy (Ober, 1936) or division of the fascia near the muscle affected* may relieve the condition.

When a normal individual stands erect, the fascia lata is a powerful brace on the lateral surface of the thigh, helping to steady the pelvis and at the same time acting as an aid in keeping the knees firmly extended.

The fibrous envelope or fascia of the thigh is divided into two layers between which are found the tensor fascia femoris, the vastus and sartorius muscles; then it drops deep to be attached to the two lips of the linea aspera. An envelope of fascia about the thigh completely surrounds it, but the fascia is thinner in the posterior femoral region than in any other portion.

This fascial sheath is, therefore, a continuous investment about the thigh, and by its division it is an enveloping sheath for various muscle groups. It also has various apertures in it through which pass important structures. In addition to this, the thickened lateral portion or the so-called "iliotibial band" serves as a strong fascial brace to the thigh as well as continuing on as the investing fascia of the leg.

EXAMINATION

In an examination of the thigh the normal anatomic landmarks must be noted. By inspection one must note whether the contour of the thigh shows evidence of atrophy or swelling. Any dilated veins or any evidence of local infection as well as any change in the contour or appearance of the skin should be noted. On palpation one may determine the presence or absence of local heat as well as the size and often the consistency of any underlying pathologic process. Measurements of the circumference should be made at various levels of the affected thigh and compared with measurements of the normal thigh. The approximate length of the femur may be determined by measuring from the tip of the greater trochanter to the margin of the articular surface of the femoral external condyle, or, if a more accurate method is desired, a roentgenogram of the femur with the

tube at a distance of 6 feet may be taken on a large film. A teleoroentgenogram or a scanogram may also be made.

A study of a roentgenogram of both the shaft and the epiphyses in the upper and lower portions of the femur will give valuable help in those cases suspected of disease, injury, bone tumors or other pathologic bone processes. In addition, roentgenograms may be made for soft tissue detail.

DISEASES

Tuberculosis

Tuberculosis of any long bone is infrequent but should be kept in mind in any chronic bone lesion that produces osteosclerosis and a local fibrous reaction. In conditions affecting the femur in which tuberculous osteomyelitis is suspected clinically, a biopsy of the bone or a guinea pig inoculation of aspirated material should be done. In tuberculosis of the long bones the sequestra are not large and are rarely multiple, but small sequestra may be seen.

In the epiphyseal area of the long bones one occasionally sees a type of destructive lesion extending from the diaphysis into the epiphysis; when this is seen it *may be suspected* that the lesion is tuberculous, although this is not always true.

Treatment. Streptomycin with the necessary surgery is the preferred treatment.

Osteomyelitis

Nontuberculous osteomyelitis (Fig. 309) of the femur is the most common disease involving the bone.

The pathology, clinical picture and general treatment of osteomyelitis are discussed in Chapter 2. The disease usually starts secondarily to infection outside the bone.

Myositis

Chronic myositis presents many more diagnostic difficulties than *acute myositis*, which is usually the result of injury. With localized chronic muscle pain, without a history of trauma, various muscle tumors may be considered When these are not present, the pain may be referred from one of the adjacent joints. Sometimes if primary muscle disease is suspected, an exploratory operation and biopsy may be necessary to determine the exact diagnosis.

Infectious myositis may be due secondarily to the more common pyogenic infections of the bones or joints. Inflammatory changes are rarely demonstrated in the muscles themselves, being seen more fre-

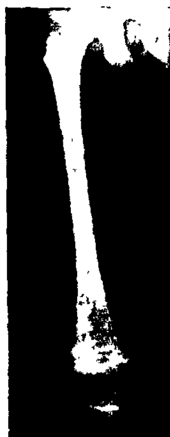


FIGURE 309. Acute osteomyelitis of the distal part of the femur. Note bone destruction. This is rarely visible within the first ten days of the disease.

quently in the connective tissue sheath and fascia enclosing the muscles. Cases of primary tuberculosis of the muscles have been reported; however, this is a very uncommon finding.

The term "fibrositis" was introduced by Gowers (Comroe, 1953) in 1904 and has gradually crept into the literature as a term indicating the syndrome of pain, stiffiness or aching, appearing in any portion of the fibrous tissue about bones and joints. The regions most commonly affected are the lower back, the gluteal region, the shoulder, the neck and the chest. It may occur as the result of a known infection but many cases are not infectious in origin. Exposure to cold, occupational trauma and a diathesis toward rheumatism are factors in many cases. However, infectious myositis is an unfortunate term for it lacks a firm pathological background and is a wastebasket phrase for a diagnosis.

SOFT TISSUE INJURIES

Soft tissue injuries may consist of injury to the soft tissue alone or to the femur and its soft tissue covering. A simple muscular injury may give rise to an acute myositis or, if in the neighborhood of a joint, to an acute synovitis or bursitis. These traumatic manifestations are usually aggravated by any active infection in the body. Usually with rest these simple muscle irritations quickly subside. If a bursa becomes infected, aspiration, or even drainage, and rest to the part are necessary. Occasionally a chronic bursitis develops which requires complete excision of the thickened bursal wall.

Rupture of the Rectus Femoris Tendon

Muscle rupture may result from overstretching or may occur during active contraction of the muscles; it is found either in the belly of the muscle itself or at the musculotendinous junction.

In the thigh the strong rectus femoris tendon may be torn from its origin at the anterior inferior spine; this may be accompanied by a small fracture of the anterior inferior spine.

Treatment. In acute cases, recumbency for several weeks with the thigh flexed allows satisfactory healing to occur. Open operation is necessary in chronic cases, in order to repair the torn tendon.

Rupture of the Quadriceps Muscle

The quadriceps muscle is more frequently ruptured in the suprapatellar region, although it does occur at other levels, giving rise to a localized collection of blood in the muscle and hemarthrosis. The patient suffers a sharp stabbing pain at the onset. Extension of the knee is impossible when rupture is complete; even though rupture is incomplete, extension always is impaired to some degree. A gap can sometimes be seen or felt at the upper pole of the patella (Fig. 310) and

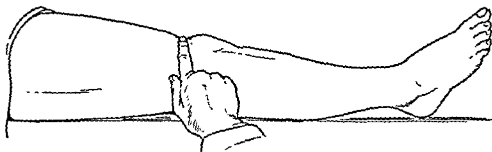


FIGURE 310. Depression suggestive of rupture of the quadriceps muscle.

can be demonstrated by roentgenogram using a soft tissue technic.

Treatment. Unless the patient's general condition contraindicates operation, early open repair of the complete rupture is always indicated. This consists of washing out the hematoma found at the site of injury and suturing the torn muscle fibers together, keeping the limb immobilized in extension from 3 to 6 weeks. After this, passive and active exercises may be instituted, but the knee should be protected by a caliper splint for the next several months, so that sudden undue strain is not placed upon the previously injured muscles.

In the chronic cases, repair can often be accomplished by weaving strips of fascia lata through the proximal and distal portions of the torn quadriceps and pulling the two ends of the torn muscle together.

Rupture of the Patellar Ligament

Rupture of the patellar ligament may occur by indirect force such as sudden contraction of the quadriceps, which the patient may make to avoid falling. There is danger also of its occurring when the knee is forcibly stretched in any form of manipulative surgery.

Treatment. This is a disabling injury and should be repaired by the use of fascia lata passed through the tibial tubercle and into the proximal portion of the patellar ligament. After this reconstruction procedure, the knee is placed in plaster in full extension for from 3 to 6 weeks, after which gradual use of the knee is permitted, protected by a brace.

The other muscles in the thigh are rarely the seat of rupture of their tendons or muscle bellies.

Traumatic Myositis Ossificans

Traumatic myositis ossificans may occur in any muscle as a result of a chronic irritation; in the adductor group of muscles the so-called "rider's bone" may be produced. The more common sites for the development of myositis ossificans traumatica, however, are in the brachialis anticus at the elbow, the quadriceps extensor muscles at the knee, and near the insertion of the Achilles tendon.

Intramuscular ossification may form within the thigh adductors, particularly in young adults. The mass is palpable and easily demonstrable in the roentgenogram (Fig. 311). This should not be confused with *progressive myositis ossificans,* which is a rare constitutional disease and is discussed in Chapter 2.

Treatment. Vigorous physical therapy consisting of massage and ex-

ercise should never be done. Immobilization and rest are recommended in the acute stage. If the "rider's bone" gives rise to symptoms of chronic discomfort its removal is desirable, but early excision is contraindicated.



FIGURE 311. Traumatic myositis ossificans in the region of the lesser trochanter. This closely resembles an ossifying hematoma.

Charleyhorse

The term charleyhorse has been defined as a soreness or stiffness in a muscle following an excessive strain. It may thus correctly be applied to any muscle, but usage limits it to injury to the quadriceps femoris.

It is most commonly encountered in direct injuries to the anterior aspect of the femur, such as occur in athletic competition. It is associated with some actual rupture of muscle fibers and is accompanied by hemorrhage in varying amounts.

Muscle strains are infrequently seen over the belly of the quadriceps. The usual strain is thus noted at or near a musculotendinous junction and it follows that the resultant hemorrhage is less than that found with direct trauma.

Injuries to the posterior surface of the femur are less frequent, because of its location and the fact that the muscle groups which are tendinous in the distal portion tend to absorb force by separating toward the lateral and medial sides.

It is a fact that strains or "pulls" near the origin of the hamstrings are more difficult to treat, i.e., are symptomatic longer, probably because of the larger muscle component at this region and the resultant increase in hemorrhage.

A second area of frequent involvement is the gastrocnemius soleus complex which, because of its large flat surface, is readily accessible to direct trauma.

Treatment. Treatment is directed at the reduction and absorption of hemorrhage early, combined with rest when it is felt that many muscle fibers are involved. The size of the hematoma, however, often determines the duration of symptoms. Thus ice for 36 hours post-injury, followed by gradual heat, gentle massage and active exercise over a period of 10 to 14 days, is the usual therapy. Strapping early and late tends to limit spread of the hemorrhage and assists in reduction of symptoms when active motion is indicated.

Complications are rare, myositis ossificans being the most frequent. Recurrence is sometimes seen if the period of therapy is inadequate. An increase in the number of hematomas in athletes seems to be directly related to early participation in predisposing athletics.

FRACTURES

Femoral Shaft Fractures in Children

In *infants* and *very young children* fracture of the shaft of the femur may be of the transverse variety (Fig. 312), although it is more commonly of the oblique type; it is caused by direct injury. Nonunion in this younger age group does not have to be feared.

Treatment. In *infants,* longitudinal traction and reduction is most easily obtained by Bryant's suspension (Fig. 313), as follows: Adhesive traction is applied to both lower extremities, and with the thighs flexed to right angles, enough traction is applied to the limbs to lift the pelvis just off the bed. This position provides satisfactory immobilization and simplifies the nursing care of the infant. Four to six weeks in this position usually produces a very satisfactory alignment and a firm bony callus.



FIGURE 312. Transverse fracture of the femur in a child.

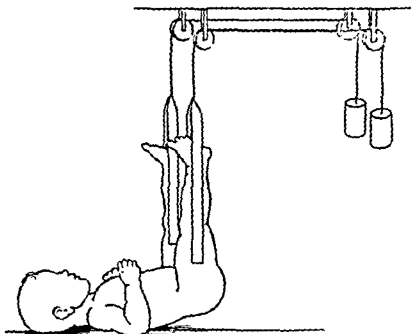


FIGURE 313. Bryant overhead traction A very satisfactory method of treating femoral shaft fractures in infants Note the elevation of the pelvis which acts as a counterweight.

In *older children* of 5 years and upward, reduction is better when made under the fluoroscope. Moleskin adhesive plaster is then applied to the lower extremity, leaving the foot out of the plaster. A plaster spica over this gives immobilization to the fracture, and longitudinal skin traction of 5 to 10 pounds is continued. Healing occurs in about 4 to 6 weeks, but weight bearing should not be allowed under 10 to 12 weeks. If there results some slight shortening or angulation at the site of the fracture, in the young child time can usually be depended upon to effect a restoration in the bone pattern. Though exact anatomic reposition is desirable in the treatment of fractures at all ages, it is gratifying to note how often restoration of the normal bone configuration results after even considerable angulation or overriding in infants and young children.

Open reduction of fractures in children should rarely be done unless there is an interposition of the soft parts between the fracture fragments, or unless it becomes necessary to relieve circulatory embarrassment.

Femoral Shaft Fractures in Adults

Fractures of the shaft of the femur in *adults* may conveniently be divided into those of the upper, middle and lower thirds of the femur.

Upper Third Shaft Fractures. If the fracture occurs *above* the level of the trochanter minor (intertrochanteric region), abduction and outward rotation of the proximal fragment (Fig. 314) are produced by the resultant action of the gluteus medius and minimus and the external rotators of the hip, and the distal fragment is displaced upward by the hamstrings and rectus, or inward by the adductor group of muscles.

Open reduction and immobilization by a Newfeld nail or some form of internal fixation such as the Küntscher intramedullary nail is recommended. Of the closed methods, Russell's traction (Russell, 1924) is the method of choice.

If the fracture occurs *below* the level of the trochanter minor in the *upper third*, the proximal fragment will be pulled into abduction, outward rotation and flexion by the iliopsoas muscle and abductors of the hip.

In treatment of both of these fractures, the distal fragment must be brought in line with the flexed, abducted fragment if the line of longitudinal pull is to be efficiently maintained. Skeletal traction through the lower end of the femur or the upper end of the tibia, with the distal fragment in line with the proximal one and in the same plane

as regards rotation, produces correction of the deformity. This type of fracture can be most successfully treated by means of a Küntscher intramedullary nail. As a rule, this type of fracture heals without difficulty following operation.



FIGURE 314. Fracture of the femoral shaft in the upper third. Note abduction and outward rotation of the proximal fragment.

If traction is used, it should be continued from 8 to 10 weeks, followed by the use of a protective brace. Weight bearing is contraindicated if traction methods are used until roentgenograms show evidence of solid bony union, usually within 3 to 4 months.

When shaft fracture of the upper third of the femur is of a simple transverse type, the Küntscher nail technic is the ideal treatment and allows earlier ambulation. If an oblique fracture, probably plate and screw fixation is treatment of choice.

Middle Third Shaft Fractures. These fractures may be of the oblique, transverse or comminuted type, the oblique being the most common. There may be marked angulation, overriding and lateral displacement, and the aim should be restoration of the normal slight anterior bowing and correction of the overriding.

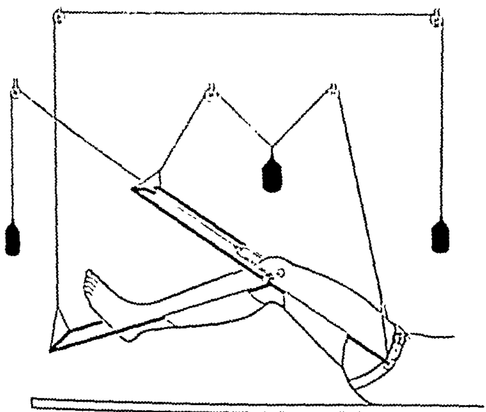


FIGURE 315. Skeletal traction, with Thomas half-ring splint and Pierson attachment.

Good results can usually be obtained by skeletal traction when the limb is maintained on a Thomas ring splint with Pierson attachment (Fig. 315) or by the use of the Küntscher intramedullary nail. If interposing soft tissues between the lines of fracture are suspected, or there is difficulty in obtaining accurate reduction, open operation with visual reduction and plating is an excellent method, although use of the Küntscher nail (Fig. 316) is preferred.

In the long oblique type of fracture of the middle third of the shaft, open operation using several large transfixion screws gives sufficient immobilization and effectively withstands the terrific muscle pull that is always a feature in these fractures. This type of fracture can be well treated also with the Küntscher rod, which will permit earlier weight bearing.

Lower Third Shaft Fractures. These occur in the supracondylar area and may be transverse, comminuted or oblique. The lower fragment is displaced backward by the pull of the gastrocnemius muscle and at the same time the proximal fragment is rotated outward by the spasm of the adductor magnus muscle as well as by the force of gravity (Fig. 317).



FIGURE 316. Fracture of middle third of femur treated by Küntscher rod. Note the rapidity of callus formation. (*a*) Before treatment. (*b*) One month after nailing, early callus is visible. (*c*) Six months after nailing, firm bony union is present.

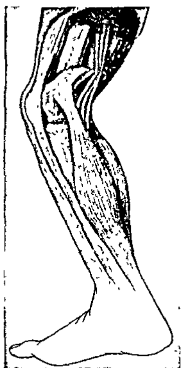


FIGURE 317. Fracture of the distal third of the shaft of the femur. The posterior displacement of the distal fragment by the gastrocnemius muscle endangers the popliteal vessels and nerves. (Babcock, *Textbook of Surgery*.)

The distal fragment is so short that it is impossible to secure effective skin traction on this fragment, and skeletal traction through the condyles of the femur, or preferably the condyles of the tibia, will be needed to reduce the displacement effectively. This fracture may be particularly dangerous because of the impingement of the distal fragment backward against the large blood vessels and nerves in the popliteal space (see Fig. 317). Accurate reduction is most essential here, and the *knee must be kept slightly flexed* on a Braun frame while the fracture is healing, to eliminate subsequent strain on the posterior ligaments of the knee joint. Although skeletal traction here is very effective, Russell's traction (Fig. 318; also Fig. 471) is simple to apply

FIGURE 318. Russell's traction. The position of the limb must be carefully checked.

and is particularly useful for this type of fracture. An open operation is rarely necessary and should be avoided if possible. Roentgenograms before, during and after the type of treatment selected should be insisted upon, for accurate reduction is very important at this site. It offers the best opportunity for restoration of knee function.

Summary. Although 3 to 6 months may be usually expected for fractures of the femoral shaft in the adult to unite so that weight bearing can be resumed without any external support, the degree of femoral healing and accurate alignment should be based on the roentgenographic appearance. On this criterion must depend the prognosis for the restoration of normal function, provided no serious soft tissue damage is present.

Malunion and Nonunion

Ununited femoral shaft fractures occasionally occur because of improper reduction or because of too early weight bearing, before the callus has become strong solid bone.

Treatment In general, the treatment can be summarized as follows:

(1) If angulation is slight, simple protection for a few months against further increase of the deformity should be carried out, using roentgenographic evidence to check the progressive union.

(2) When the anterior or lateral bowing is marked, closed correction should rarely be attempted. Usually an open operation is the method of choice.

When there is no overriding, but simply a malunion, an incomplete wedge osteotomy may be done at the apex of the deformity, the area packed with bone chips, the wound closed and plaster applied. A few weeks later the plaster is divided at this level. The soft callus hinders displacement and the deformity is corrected by manipulation under the fluoroscope, after which the plaster spica is reinforced and united at the level of its division (Moore, 1947).

(3) If, however, the malunion is severe and complicated by overriding of the fragments, or if a frank nonunion (Fig. 319) is present, a more extensive open operation is desirable. The bone cortices at the fracture site must be completely freed, and *in the pseudarthrosis cases,*

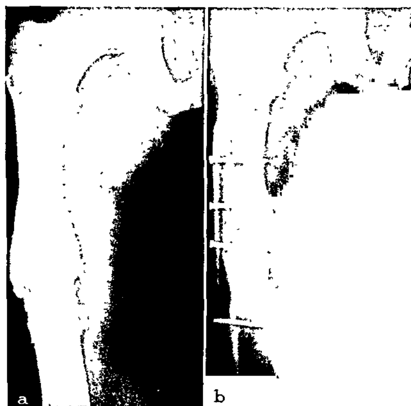


FIGURE 319 Old nonunion of femoral shaft fracture. (*a*) Before treatment, (*b*) massive bone graft and bone union.

scar tissue involving bone and soft tissues must be excised. The bone ends are then approximated and held by some form of internal fixation. We may employ (*a*) a massive bone graft (Campbell, 1956), either single or dual, packing bone chips from the ilium or tibia about the site of osteotomy; (*b*) an intramedullary Küntscher nail which extends well above and below the site of fracture if the nonunion is in the upper or middle third; or (*c*) a vitallium plate with six screws. When properly applied, the Küntscher nail produces firm immobilization of the fragments in good alignment and permits early weight bearing—all very desirable features when trying to correct deformity and stimulate union.

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11

The Knee

APPLIED ANATOMY

The knee is the largest and one of the most important joints in the body. Entering into its formation are three bones: the femur, the tibia and the largest sesamoid bone in the body, the patella. It is regarded as a hinge type of joint, an analogue of the elbow. The strength of the joint depends very little upon its bony conformation but rather upon the powerful ligaments in and about it and the muscles that reinforce the joint (Christian, 1915).

The lower extremity of the femur consists of two articulating surfaces with an intercondylar notch between. The two surfaces are continuous in front, and the posterior surface of the patella articulates with them. The lateral condyles of the femur and tibia are broader and flatter and receive most of the weight. The medial condyle of the femur is longer and elliptical and on a lower level than the lateral, thus permitting the leg to swing out during the action of flexion to prevent interference with its fellow condyle. The posterior portions of the condyles are very sharply curved to allow increased speed in action.

The upper shallow articular surfaces of the tibia with the bifurcated spine between make up a portion of the knee joint. The strong anterior and posterior cruciate ligaments, running from this spine upward to be attached to the outer and inner sides of the intercondyloid notch respectively, limit anteroposterior motion of the femur on the tibia.

The next important internal structures of the knee joint are the semilunar cartilages (internal and external), almost circular menisci, attached in front near the base of the anterior cruciate ligament and behind near the posterior cruciate base. The internal cartilage is more closely attached to the capsule of the joint and is, therefore, more easily subject to injury when the leg is abducted and rotated outward on the

femur. Binding the cartilages loosely to the underlying periphery of the tibia are the short fibers called coronary ligaments.

The other ligaments of the knee are: (1) the internal lateral (medial) ligament, a broad flat band whose deep fibers are attached intimately to the periphery of the internal semilunar cartilage and the capsule of the joint as well as to the femur above and the tibia below, along the inner side of the joint; (2) the external lateral ligament, consisting of two bundles of fibers, but practically all one ligament, running from the femur to the upper end of the fibula on the outer side of the joint; (3) the posterior ligament (ligament of Winslow). The central portion of this posterior ligament, the strongest portion, is an expansion from the semimembranosus muscle and forms the floor of the popliteal space, upon which rests the popliteal vessels. (4) The powerful patellar ligament is a part of the quadriceps muscle group and runs from the patella to the anterior tubercle of the tibia, into which it inserts (Jackson, 1942).

The principal muscles that strengthen the joint are: in front, the quadriceps with its capsular expansions; behind, the two heads of the gastrocnemius and popliteus. The popliteus and the biceps also greatly strengthen the outer side of the joint. On the inner side are the semimembranosus, semitendinosus and gracilis muscles (Kling, 1938).

The synovial membrane is the largest in the body. The so-called ligamentum mucosum, which is attached to the front of the intercondyloid notch and to the lower extremity of the patella, is a fold of the synovial membrane. From the lateral edges of the ligamentum mucosum extend fringelike masses of fat, the ligamentum alaria (Spalteholz, 1947). The membrane is the lining of the joint and is continued above into a large pouch, the quadriceps or suprapatellar bursa. Behind the patellar tendon and projecting into the anterior portion of the joint is the infrapatellar fat pad, which is extrasynovial and changes shape with every movement of the joint. This pad is connected with the intercondylar notch of the femur by the ligamentum mucosum.

Blood Supply. The arteries that supply the knee joint are the articular branches of the popliteal, the anterior and posterior recurrent branches of the anterior tibial, the anastomotica magna of the femoral, and small branches from the external circumflex.

Nerve Supply. The nerve branches are those from the femoral, common peroneal and tibial nerve trunks, while the obturator nerve sends a branch to the posteromedial aspect of the knee.

Epiphyses. The lower epiphysis of the femur is the largest in the

body. Its epiphyseal center can be seen at birth in roentgenograms; bony fusion between the diaphysis and epiphysis occurs at about the nineteenth year (Fig. 320).

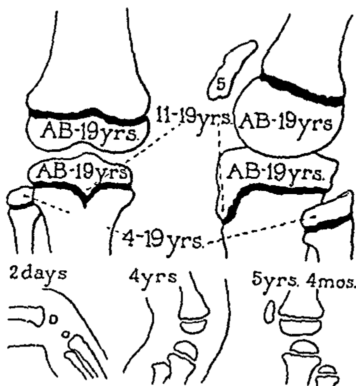


FIGURE 320. Ages at which appearance and fusion of the epiphyses occur. AB at birth.

The anterior tubercle and the upper epiphysis of the tibia usually ossify from a single center, uniting with the diaphysis about the nineteenth year. It is present at birth and presents several interesting facts worthy of note. The anterior tubercle of the tibia is a downward projection of the upper epiphysis of the tibia, making its appearance about the eleventh year, and into it is inserted the patellar ligament. Because of the widely separated appearance from the diaphysis, it may give the impression that the tubercle of the tibia is fractured. Occasionally the tubercle appears to develop from two separate centers of ossification, and during adolescence this tonguelike projection may be the seat of an osteochondritis, the so-called Osgood-Schlatter's disease.

The patella appears in the roentgenogram around the fifth year, making its appearance just opposite the epiphyseal line of the lower end of the femur, although at times it ossifies through two centers (bipartite patella) within the cartilage envelope. It reaches its full bony development around puberty or about 14 years of age.

The upper epiphysis of the fibula is not evident until the fourth year and sometimes becomes completely ossified by the sixteenth year, although union is not constant until the nineteenth year.

In summary, therefore, during the first three years the only epiphyses evident about the knee are those of the lower end of the femur and the upper epiphysis of the tibia, and after the nineteenth year complete ossification of all the epiphyses to the diaphyses has occurred.

EXAMINATION

Because the knee joint depends so largely for its integrity upon its ligaments and muscles, injuries to the soft tissue frequently give rise to joint difficulty. The bones making up the joint are the longest in the body, hence their lever action is exceptionally great, which necessarily means the joint must be firmly braced. The functions of this joint are that of support and mobility, it being a modified hinge joint with a small amount of rotation; this rotation could be practically ignored except that injury is so frequently associated with this motion.

The extent of the synovial membrane and the position of the cruciate ligaments and the semilunar cartilages add much to the complexity of the joint and produce opportunities for traumatic effects not present in other joints.

The normal surface contour can be obliterated by increased joint fluid, at which time the bulging appearance noted on either side of the patella will be quite evident, and the fullness and swelling in the suprapatellar region will become aggravated on flexion. With an increase in the joint fluid a "clicking" of the patella against the underlying femur can be demonstrated, as shown in Figure 321. This is called "ballottement" of the patella. Normally the joint can be passively and actively extended to 180 degrees or slightly beyond, while flexion is limited by the calf of the leg coming in contact with the posterior surface of the thigh muscles (Fig. 322). A horizontal surface groove indicates the line of the tibial articular surface, and at this region the semilunar cartilages are located. The tendon of the biceps is inserted into the head of the fibula which is at a level opposite the anterior tubercle of the tibia. The iliotibial band can be seen and felt in front of the biceps tendon. Normally the patella is freely movable and cannot be dislocated, since it is restricted not only by soft tissue, but by a slightly increased elevation of the anterior surface of the condyles of the femur. In congenital or acquired dislocation of the patella, it usually

dislocates laterally due to abnormalities in either the soft structures or the bony configuration of the joint.

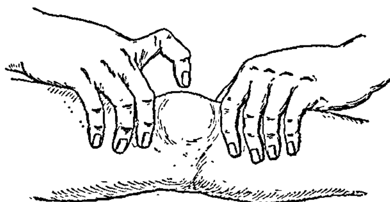


FIGURE 321. Eliciting the "tap" or "click" of the floating patella in synovitis of the knee. The hands are used to gather the fluid under the patella so that the index finger may percuss and elicit the "tap" or "click." (Moorhead.)



FIGURE 322 Normal range of knee motion in the young adult.

DISEASES

Tuberculosis

Tuberculosis of the knee joint was formerly called "white swelling," or tumor albus, and is next in frequency and importance to that of tuberculosis of the hip. Over 50 per cent of the cases are in children under 5

years of age, but only a very small percentage of bone and joint tuberculous cases have pulmonary involvement.

Pathology. As in all tuberculous lesions, however, the joint involvement represents the local manifestation of a systemic disease. Although it may be primarily synovial in origin, it far more frequently arises from the bone and spreads into the joint cavity. The metaphysis of the femur or tibia is the usual site, although it may even arise in the patella or the head of the fibula and involve the knee joint. Whether osseous or synovial in origin, there is a secondary synovitis.

The synovial membrane becomes thickened, adhesions form and the tuberculous granulation tissue or pannus advances from the periphery, medially, and destroys the articular cartilage of the joint, both on the articular surface and subchondrally. Tuberculous fluid appears early within the joint and is of a thin, watery consistency. Scattered through it are flaky masses of degenerated joint tissue like curds in whey. Abscesses occur in about one-third of the treated cases and in a larger percentage of untreated cases. The abscess may rupture into the surrounding soft tissue or through the skin to form a chronic draining sinus; these are the cases that formerly had such a high mortality rate.

Clinical Picture. Because the knee joint is not covered by fleshy muscles, slight effusion will produce a very perceptible change in contour. The history is almost always of a chronic and progressive disability of the knee. The time of onset of early disability should be carefully sought. The signs and symptoms of tuberculous joint disease are limp, pain, muscle atrophy, local heat, sensitiveness, swelling, muscle spasm, limitation of motion and joint distortion.

In any young child presenting chronic progressive joint disability, tuberculosis must be seriously suspected. The limp and limitation in extension of the knee are very early signs. Other evidences of local inflammation soon make their appearance. In the late stages secondary changes of outward rotation of the tibia on the femur and posterior subluxation of the leg on the thigh at the knee are fairly common, owing to the underlying bone destruction and persistent muscle spasm. As the joint surfaces are often actually destroyed, there is frequently a definite shortening of the limb. Gross deformity is produced and involvement of the epiphyseal plate with subsequent growth disturbance may occur.

Roentgenographic Findings. Early decalcification of bone and soft tissue swelling (Fig. 323) along with later narrowing of the joint

space and destruction of the underlying bone are all striking features of tuberculosis of the knee joint.

Examination. Both knees should be examined while the patient is lying on the table and the contour of the joints compared to detect early

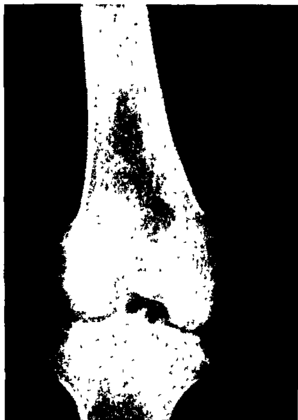


FIGURE 323. Tuberculosis of the knee joint. Note bone destruction.

joint swelling Muscle atrophy, especially of the quadriceps, is frequently noted early. The joint should be examined for increased joint fluid by "ballottement" of the patella. This consists of laterally compressing the knee joint with both hands and at the same time the index finger pushes the floating patella against the underlying bone, giving the characteristic "click" if synovitis of the joint is present (see Fig. 321) The joint should be carefully palpated for areas of tenderness and for periarticular thickening of the soft tissues, and then its range of motion carefully determined both by active and passive movement. It should be observed whether the leg is rotated outward on the femur by the pull of the biceps and whether there is a subluxation backward of the tibia on the femur. The diagnosis can usually be made from the history, physical examination, tuberculin test and roentgenogram; when the diagnosis is uncertain, a guinea pig culture of the aspirated mate-

tial or a biopsy of the diseased portion of the synovial membrane should be made.

Differential Diagnosis. Tuberculosis of the knee joint is as a rule confined to a single joint; this important point often aids in differentiating it from a general or constitutional condition such as rheumatism, scurvy or rickets. To rule out the nontuberculous arthritides in the early stages is not always easy, although usually the history, roentgenogram and laboratory data will clearly differentiate between the two.

Prognosis. It should not be expected that normal motion will ever result in any weight-bearing joint affected by tuberculosis. Only under the most favorable condition will conservative treatment produce even moderately satisfactory function, and this only in a very small percentage of cases. The mortality rate is not high unless the patient has multiple abscesses or positive lesions of tuberculosis in other portions of the body.

Treatment. *Children.* A combination of both conservative and operative measures is necessary in the great majority of cases. The natural defenses of the body should be built up to their maximum before fusion is advisable. Therefore, as a preliminary to surgical fusion, conservative treatment, consisting of streptomycin, a nutritious diet, fresh air, heliotherapy, rest and protection to the joint by traction, braces or plaster for a few months, is advised, and the disease process should be checked by roentgenograms.

At the time of knee fusion, care must be taken not to injure the epiphyseal plate, but as much as possible of the gross disease should be removed. The two raw bony surfaces of the tibia and femur, after having been stripped of their cartilage, are allowed to fuse in the extended or almost fully extended attitude, depending somewhat on the future type of work these children may do. If an active, laboring type of work is anticipated, the fully extended position is desirable; if a sedentary, clerical occupation seems probably, the knee should be fused in slight flexion.

Adults. A protracted period of conservative care is rarely justified for adults. The economic need for a return to the individual's occupation is usually a pressing one and early fusion is recommended. Varying degrees of joint destruction are encountered, and the more extensive the disease the longer will be the time required for a solid bony fusion following surgery. Preoperative and postoperative use of streptomycin is advised. Usually the joint will need a period of 3 to 6 months' immobilization

in plaster postoperatively before the roentgenogram will demonstrate bony union. Protection by brace or casing (Fig. 324) is indicated for a few months after the removal of plaster fixation.

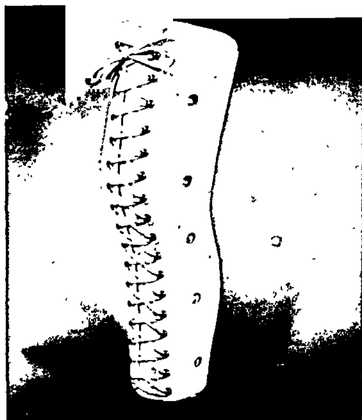


FIGURE 324. Light celluloid knee casing. This may be used following knee fusion and removal of plaster fixation. It is made on a mold of the knee.

In the advanced adult case with multiple draining sinuses a severe toxic reaction often develops; in these cases a midthigh amputation becomes a life-saving measure. Streptomycin therapy is proving to be very useful and should be employed in all cases with sinus formation.

Acute Infectious Arthritis (Pyarthrosis)

The pyogenic organisms producing an acute arthritis are many. The most common are the staphylococci and streptococci of various strains, the *Diplococcus pneumoniae,* the gonococcus as well as many less common organisms. If an acute synovitis arises in a joint in the absence of trauma, it is usually infectious in origin.

Pathology. See Chapter 2.

Clinical Picture. The signs and symptoms in an *acute arthritis* give all the local evidence of an inflamed joint. The knee joint is usually

flexed, hot, swollen, red, and painful on the slightest movement. The temperature is markedly elevated and a high leukocyte count is present.

Treatment. If the condition is seen early, aspiration may reveal a clear or cloudy fluid. Repeated aspirations, chemotherapy to which the offending organism is sensitive and complete rest of the joint in plaster or on a splint may suffice.

As a rule, however, the joint showing evidences of acute inflammation will disclose purulent material on aspiration. Then incision and drainage with systemic use of large doses of penicillin, streptomycin or aureomycin are necessary. These patients are often dangerously ill and delay may result in permanent joint destruction. An *acute suppurative arthritis is an emergency* and requires emergency treatment. Repeated aspiration, washing the joint out with normal saline solution, and large doses of penicillin employed systemically and locally may salvage joint function occasionally.

When incision and drainage are necessary, lateral incisions are made on either side of the joint, and a small rubber tissue drain is carefully inserted down to, but not into, the synovial membrane and held in this position by one suture. The joint should be supported on a splint but early active motion should be encouraged.

Acute Gonococcal Arthritis

In acute gonococcal arthritis 75 per cent of the cases present involvement of more than one joint, occurring 2 or 3 weeks after the onset of the gonococcal infection. Males between the ages of 20 and 30 are most frequently affected. The knee is by far the most commonly affected joint. There are the serous, dry, fibrinous and suppurative types; the latter type is very destructive and if not controlled results in bony ankylosis of the joint.

Clinical Picture. Signs and symptoms range from only a slight swelling or discomfort in one or more joints up to severe, extreme pain, redness, increased local heat, swelling and marked muscle spasm, the joint being exquisitely painful on the slightest movement.

Roentgenographic Findings. An acutely inflamed joint rarely shows any bone destruction within the first few weeks and little, if any, bone decalcification. There is periarticular swelling with effusion. The picture of gonococcal arthritis may sometimes be suggestive of tuberculosis, but can be differentiated from it by the history and the rapidity with which the process appears and subsides following immobilization and penicillin therapy. In the late stages of the pyogenic infection of the

knee joint, obvious thinning of the joint space indicates cartilage destruction, which may be followed by roughening of the joint surfaces. Sometimes bony ankylosis follows.

Treatment. In the acute stage incision and drainage are rarely indicated. The increasing benefit of chemotherapy, particularly sulfadiazine and penicillin, has been striking. These agents have a definite inhibitory effect on the growth of the gonococcus organism. Sulfadiazine, 15 Gm. every four hours after an initial dose of 60 Gm., and penicillin, 200,000 to 300,000 units in twenty-four hours intramuscularly, have revolutionized the therapy and largely outmoded surgery.

Syphilitic Infection

Infection of the knee joint is uncommon in the early stages of acquired syphilis. An *arthralgia* forms a part of the clinical picture in the

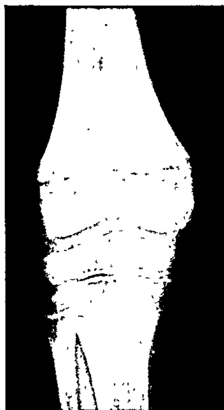


FIGURE 325 Bone syphilis of the lower diaphyseal portion of the femur. Note spotty decalcification in the diaphysis and widening of the epiphyseal plate.

secondary stage of acquired syphilis. The joint may be painful and irritable when at rest and, therefore, is worse at night. There is very little muscle spasm and no local swelling, increased heat or any tend-

ency to deformity. The roentgenogram (Fig. 325) is sometimes of value but one must depend largely upon the history and laboratory data in these forms of infection. An acute or chronic synovitis may develop *as a complication of late secondary or early tertiary syphilis, due to* primary involvement of the synovial membrane, and this may result in chronic hydrops of the joint.

Charcot's Joint. In the quaternary stage of the acquired form of syphilis we have the so-called *Charcot's joint,* which is a painless, destructive swelling of the joint in which irregular bony masses of the *joint structure become loose bodies within the joint. This is accom*panied by severe laxity and insecurity of the joint. Cartilage degeneration and disorganization are found in these neuropathic joints, which represent a late *manifestation of acquired syphilis. Any joint may* become involved, but the knee is most frequently affected. From roentgenograms, it might be assumed that such extensive destruction required a long period of *time, but on the contrary it may be quite rapid. In* spite of this extreme destruction, the painlessness of these joints is the striking feature. Roentgenograms (see Fig. 70) show that the bones are really *denser than normal, suggesting that the joint must have been* in constant use.

Even the neuropathic joint, however, may give rise to an aching sensation due to the excessive stresses and strains placed on the periarticular soft tissues. Braces are needed to support these unstable knees and occasionally fusion of the joint is the method of treatment.

Clutton's Joint. In hereditary syphilis a symmetrical chronic synovitis of the knees, which is exceedingly resistant to treatment, may develop in late childhood. *The affection is only mildly disabling, and* the other stigmata of congenital syphilis, such as Hutchinson's teeth, a history of a previous keratitis, or periostitis, should be looked for before making the above diagnosis.

SOFT TISSUE INJURIES

Contusions of the muscles surrounding the knee joint are frequent and give rise to most of the same symptoms seen in an intra-articular injury — *ecchymosis and hematoma formation under the skin. If the* hematoma is large and fluctuant, it can be aspirated. The hematoma may be caused by rupture of some large superficial vein or by tearing of muscle fibers. *Firm adhesive strapping following aspiration may also* prevent its recurrence (see also Hemophilia, Chapter 2).

Bursitis

A number of bursal sacs are located about the knee, perhaps eighteen or more, but they are not all of clinical importance.

Anteriorly the prepatellar bursa, situated in the subcutaneous tissues between the skin and the patella, may often be enlarged, constituting in the chronic cases the so-called "housemaid's knee." This bursa is normally present and injuries may cause it to become enlarged and lobulated in shape. It usually has very thin walls, but they do become thickened as the result of irritation.

The suprapatellar bursa communicates with the joint and is part of the knee joint, becoming distended in any intra-articular effusion.

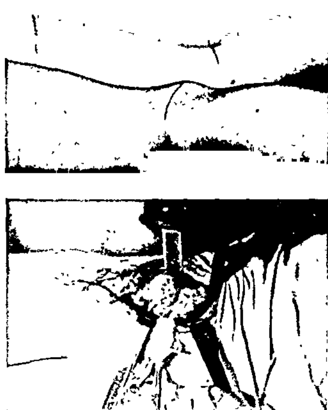


FIGURE 326. *Upper,* Baker's cyst. *Lower,* exposure of cyst in the popliteal space.

The deep infrapatellar bursa, lying between the skin and the anterior tubercle on the under surface of the patellar ligament at its insertion into the upper end of the tibia, does not connect with the joint.

Another bursa lies beneath the internal head of the gastrocnemius

muscle and usually communicates with the joint, sending a prolongation between the gastrocnemius and semimembranosus muscles. This is the most important posterior bursa and may become enlarged, pointing in the popliteal space. An evagination from the posterior pouch of the synovial membrane, protruding into the popliteal space, may also be found. Either of these last two types of bursae is called a *popliteal* or *Baker's cyst* (Fig. 326).

There is a small superficial *pretibial bursa* which overlies the insertion of the prepatellar ligament. This may become enlarged, tender and sensitive to pressure. Aspiration and strapping with adhesive plaster usually suffices in cases of pretibial bursitis.

As stated, a number of other bursae are occasionally found about the joint, and under the effects of trauma these may develop around the insertion of any of the muscles in this general region.

Treatment. In any acute bursitis, rest and cold applications render the patient more comfortable, but as soon as possible one should aspirate (Fig. 327) to relieve the tension and determine the fluid content. The purulent bursae require early incision and drainage. In the chronic bursae that develop about the knee joint, careful excision of the entire cyst is the method of choice.

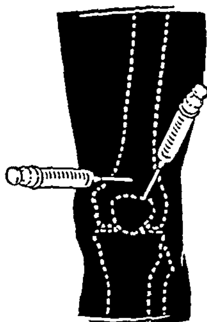


FIGURE 327. Sites of aspiration. For both sites, the needle is inserted into the suprapatellar bursa.

Traumatic Synovitis

Traumatic synovitis results from a contusion to the joint capsule of the knee. This bruising of the capsule produces an effusion from the

capillaries in the synovial membrane; this so-called "water on the knee" is a bloody, synovial fluid, an excess of synovial fluid plus hemorrhage. If the trauma is minimal, or if the synovitis becomes chronic, the synovial fluid appears straw-colored and viscid.

Treatment. Treatment should be aimed toward shortening the disability period and minimizing the amount of fluid allowed to accumulate. Hemorrhagic synovitis occurs frequently in athletic injuries and the immediate treatment is rest to the joint with the application of cold compresses for 1 or 2 hours, followed by aspiration. Then the knee is snugly bandaged with a compression bandage placed over sheet wadding and longitudinal strips of sponge rubber applied on either side of the patella. Later, aspiration and bandaging may be repeated if necessary.

Intermittent Hydrarthrosis (*Intermittent Hydrops or Synovitis*)

Intermittent hydrarthrosis is a rare type of painless synovitis occurring most frequently in young adult females. It is of interest to note that all the recorded cases have been in the white race. It occurs principally in the third and fourth decades. Heredity, trauma, infection or allergic phenomena may appear to explain the individual case; the exact etiologic agent, however, is still unknown. It somewhat resembles in its behavior the angioneurotic edema phenomenon. In some cases it seems to be related to the menstrual cycle and in others appears to be infectious or allergic. In the menstrual type of intermittent hydrops one or both knees are rapidly distended by synovial fluid, but this is not accompanied by much heat, fever, pain or tenderness. After a few *days the effusion may rapidly subside and spontaneously disappear*, to recur at the next cycle; between attacks the knee contour and the synovial membrane appear almost normal. Although the knee is the joint principally affected, cases have been reported in other joints. All cases of intermittent hydrops, however, do not follow this direct relation to the menstrual cycle, and the cause of the intermittent chronic synovitis may be difficult to determine

Treatment. Radiation therapy has been used with some relief, but the most satisfactory treatment if this chronic effusion continues is synovectomy.

Muscle Injuries

Muscle ruptures, both partial and complete, may occasionally be seen, particularly (1) *rupture of the quadriceps tendon* and (2)

rupture of the patellar ligament. In the former a definite tender depression can be felt above the superior border of the patella, associated with a bloody effusion into the knee joint which causes swelling. In the latter the torn patella ligament can be easily palpated. In both of these injuries full active extension of the knee is difficult. Such ruptures may be produced by forcibly stretching a stiff knee or by a sudden contraction of the quadriceps muscle to prevent one from falling. The patient cannot lift the heel off the bed if rupture is complete.

Treatment. In rupture of a few fibers, simple rest for a few weeks with the joint on a splint in extension may be all that is necessary; however, if the tear is complete, it is necessary to repair it surgically. The limb is then immobilized in extension for from 6 to 8 weeks and then a course of physical therapy is given, carefully guarding the joint against overstrain by having the patient temporarily wear a kneecap type of brace (Jones cage brace; see Fig. 489).

Snapping Knee

This represents minimal incongruities of the articular surfaces of the femur and tibia and is accompanied by a clicking or snapping. This can be frequently demonstrated by an audible snap as the patient actively and voluntarily contracts his joint musculature. It may be found also in cases with ligamentous relaxation or semilunar cartilage tears or irregularities.

Passively no limitation of motion may be revealed, but the patient may complain of an ache in the knee and be more disturbed by the clicking than by the disability, which is often minimal.

Treatment. Protection of the knee by an Ace bandage or a light brace may relieve the patient, but many cases require exploration. A discoid cartilage (Fig. 328) is occasionally found producing these symptoms, and when it is present its removal is indicated.

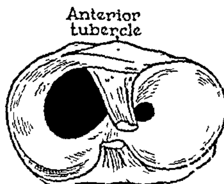


FIGURE 328. *Left,* normal internal semilunar cartilage, *Right,* discoid semilunar cartilage.

Tears of the Semilunar Cartilages

The term "internal derangement of the menisci" embraces a wide variety of conditions, and applies particularly to those conditions affecting the semilunar cartilages (Fisher, 1933).

Injuries to the internal (medial, inner) and external (lateral, outer) semilunar cartilages constitute the most frequent types of internal derangement of the knee joint. The internal cartilage is injured almost ten times as frequently as the external, due to its intrinsic anatomy.

The *internal semilunar cartilage* is predisposed to injury whenever there is a sudden internal rotation of the femur upon the fixed tibia, especially when the knee is abducted and slightly flexed. This is the attitude of the knee during the golf swing or when pivoting sharply in other forms of athletic games. The anterior portion of the cartilage is more frequently injured and it may lodge between the joint surfaces,

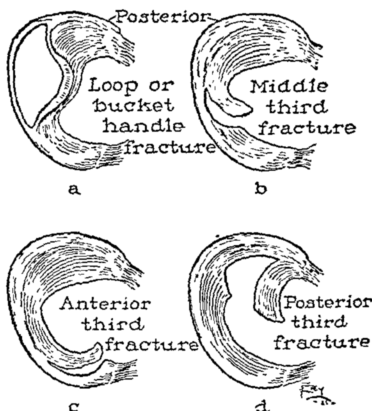


FIGURE 329. Common types of fracture of the medial semilunar cartilage. (Henderson, M. S, *Surg. Clin. North America.*)

preventing complete extension and giving rise to "locking." There are many ways a tear may follow undue trauma subsequent to the original injury, and these knees are thereby rendered more susceptible to locking.

The tearing may occur in the middle third, posterior third or anterior tip of the cartilage. The "bucket-handle type" in which the tear extends longitudinally in the meniscus is by far the most frequent, though all tears give rise to limitation of movement at one time or another (Fig. 329).

The history of the method producing the derangement should be carefully obtained. Often, *but not always*, the history is given of locking of the knee which recurs under similar circumstances. Localized tenderness over the semilunar cartilage and limitation of complete extension, with varying amounts of synovitis, are the most characteristic features, and although the cartilage may become partially reduced, some impairment of the joint is usually present. The patient always feels insecure, for he realizes that a little extra twist will again throw the cartilage out of its normal position. If, however, the bucket handle type of displaced torn cartilage lies in the intercondyloid notch region, full extension is often obtained. Following cartilage injury, atrophy of the quadriceps will develop very quickly, which will further limit the efficiency of the joint.

The *external semilunar cartilage* produces similar signs and symptoms, except that they are referred to the lateral side of the knee. Roentgenograms of either condition usually yield very little information, although there may be a slight narrowing of the joint space on the affected side; occasionally air injection may lead one to strongly suspect a tear of the internal or external semilunar cartilage. The clinical picture of localized pain, synovitis, and quadriceps muscle atrophy are the most important signs.

Treatment. Treatment for tearing of the internal or external semilunar cartilage is essentially the same, i.e., removal of the affected semilunar cartilage. The operation is not a difficult one, and as the results are so satisfactory from a functional standpoint, one may not hesitate to advise removal if there have been one or more recurrences of disability. Figure 330 shows the usual operative approaches to the knee for cartilage removal; however, if a thorough inspection of the joint is desirable, the medial or lateral patella incision should be used (utility type).

Cysts of the Semilunar Cartilages

Cysts of the semilunar cartilages are rarely encountered. However, in contradistinction to the frequency of injury to the medial meniscus, the lateral meniscus is more often the seat of cystic formation. These

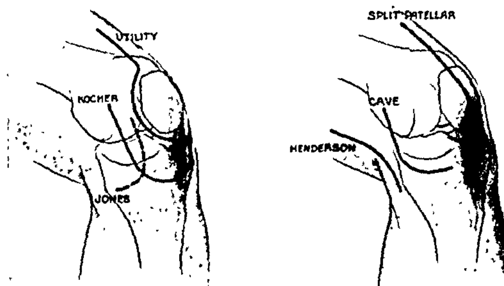


FIGURE 330. Incisions about the knee joint.

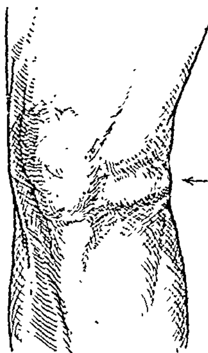


FIGURE 331. Cystic mass arising from the external semilunar cartilage.

cysts are probably cartilaginous rests which, following trauma, undergo degeneration and form multiple pseudocystic areas which are filled with yellowish fluid or soft gelatinous material. They are not true cysts from a histologic viewpoint. They enlarge and become obvious following injury to the knee, resulting in a dull ache about the affected cartilage. A definite mass (Fig. 331) can be noted, usually on the

outer side, when the knee is in complete extension. Complete excision of the affected cartilage is indicated whenever the diagnosis is made.

Discoid Cartilage

This type of cartilage is a congenital anomaly (see Fig. 328). During the embryologic development of the menisci, the early circular shape changes by absorption of the central part into the semilunar shape. If this fails to occur, the discoid meniscus results. It may be bilateral but more often only the lateral meniscus is affected. Clinically it may cause a "clunk" sound when the knee is moved and a palpable jog in flexion or extension with associated pain. Excision of the meniscus is indicated.

Calcification of Cartilage

The *primary type* of calcification is considered a degenerative change, found in the older age group, in which the calcium is laid down in parallel layers involving the entire length of the meniscus. The *secondary type*, which results from local trauma, occurs in the younger age group.

Clinical Picture. In the affected knee, the clinical picture varies from a mild soreness to severe pain and locking, localized swelling and limitation of motion; the condition may or may not be complicated by tears of the meniscus. Although the history is suggestive of some derangement of the menisci, roentgenograms show clearly whether one or both menisci of either or both knees have undergone calcification.

Treatment. Unless the calcification is causing a marked degree of pain or presents the "locking" syndrome, physical therapy may be successful in relieving the patient of symptoms. Excision is reserved only for the severely painful case which has not responded to physical therapy.

Rupture of the Internal and External Lateral Ligaments

Rupture of a lateral ligament seldom occurs without some injury to the adjacent semilunar cartilage.

Ruptures of the internal (medial) collateral ligament are caused by strains which are the result of forceful eversion of the foot and abduction of the knee, generally when the knee is slightly flexed. The external ligament may be ruptured by forceful adduction of the internally rotated knee.

Clinical Picture. These ruptures will result in an increase in the lateral mobility of the knee with sensitiveness over the affected ligament. If the internal lateral ligament is ruptured, the tenderness is more acute over its inferior attachment. The acute symptoms are synovitis, local tenderness and ecchymosis. There is weakness on movement of the knee and often a slight feeling of catching within the joint. A widening of the joint space on the affected side can be produced passively and demonstrated by roentgenogram.

Treatment. In a simple case of rupture of a lateral ligament, complete rest of the knee in full extension for 3 or 4 weeks may suffice. During this time splints can be removed for daily physical therapy. If the injury is more severe, no movement of the joint, active or passive, should be allowed. Sometimes the attachment of the internal semilunar cartilage is also torn when the internal lateral ligament is ruptured, and in such instances it is necessary to operate rather promptly. In order to overcome muscle atrophy, "setting" exercises of the quadriceps muscle should be begun immediately after the injury. Walking without protection to the joint should not be allowed if there is any sensitiveness over the torn ligament or pain on passive abduction or adduction of the knee.

A knee brace should be used when the patient starts to walk. Also, if the heel of the shoe on the affected side is raised ¼ inch, strain on the ligaments is lessened.

If the injury is more severe and the ligaments are relaxed, causing lateral instability of the joint, an open operation, using fascia lata to reconstruct the lateral ligament, is advised; on the other hand, if the medial ligaments are torn, it may be necessary to attach the tendons of the gracilis and semitendinosus muscles to the internal condyle of the femur, thus giving the needed stability. The operation devised by Mauck (1926) for internal lateral ligament relaxation consists of tightening the ligament by sliding its insertion downward on the tibia by means of a bone flap.

Rupture of the Cruciate Ligaments

The anterior cruciate ligament prevents anterior displacement of the tibia on the femur, whereas the posterior cruciate ligament prevents posterior displacement; both limit rotation of the tibia. Rupture of the cruciate ligaments occurs only from severe trauma. Hyperextension of the knee with internal rotation of the tibia on the femur may produce a rupture of the anterior cruciate ligament, and any force displacing the

tibia backward on the femur when the knee is slightly flexed may cause rupture of the posterior cruciate ligament.

In those cases with demonstrable increased laxity in the antero-posterior plane of the knee (drawer sign), one must also look for accompanying injury to adjacent bones and soft tissues. The drawer sign (Fig. 332), if positive, indicates rupture of one or both cruciate ligaments. Extreme swelling and marked instability of the joint results if the rupture is complete.

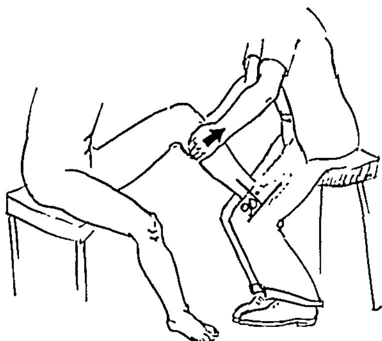


FIGURE 332. The drawer sign. Undue laxity denotes cruciate rupture.

Treatment. After known recent injury to one or both cruciate ligaments, the knee should be immobilized in extension in plaster for a period of at least 8 weeks and then a snug-fitting Jones knee cage should be worn for the next 3 months. In the older cases, in which instability is the outstanding complaint, various operative reconstructive procedures have been advocated. A rather major operation for this condition is the Hey-Graves technice, in which a strip of roled fascia lata is passed through a tunnel running laterally from the femoral condyle, downward and passing through the knee joint and through the medial tibial tuberosity. It is then attached to the medial femoral condyle (Campbell, 1956). It must, however, be borne in mind that a portion of this resulting instability from cruciate tears is due to the weakness of the muscles surrounding the joint, particularly of the quadriceps, so that each case should be subjected to a long course of

muscle training and strengthening before reconstructive operations are advised (Campbell, 1956).

FRACTURES

Fractures of the lower end of the femur that enter the knee joint are usually the result of direct violence. When the fracture is supracondylar, the proximal end of the distal fragment will be tilted posteriorly by the backward pull of the heads of the gastrocnemius muscle. The fracture may be transverse or T-shaped, entering into and splitting the condyles, or may involve only a single femoral condyle.

Fractures of the patella occur fairly frequently and are caused by either direct or indirect violence, being transverse, longitudinal or comminuted.

Fractures of the upper extremity of the tibia may be transverse, T-shaped or Y-shaped, or may involve one condyle only. They are the results of direct injury. A common site is one of the tibial plateaus. Fracture of the tibial spine or anterior tibial tubercle occasionally occurs from direct injury to the knee in the first instance and sudden contraction of the quadriceps muscle in the latter.

Lower Femoral Fractures

In fractures about the knee, the normal contour of the joint is soon completely obscured by posttraumatic swelling. Pain, tenderness, limitation in motion and crepitus may suggest the diagnosis, but roentgenograms should always be taken. Whenever the fracture enters into the knee joint proper, the situation is more serious; in this type of fracture occasionally the popliteal artery, peroneal nerves, cruciate ligaments or semilunar cartilages may be injured in addition to the bone.

Treatment. *Because of the deforming pull of the gastrocnemius* group of muscles, fractures of the lower end of the femur should always be treated with the knee in slight flexion; if the fragments can be satisfactorily and easily manipulated a closed reduction may suffice. If the fracture is of the transverse supracondylar variety only, Russell's traction can be used very satisfactorily in the majority of cases (see Fig. 318).

Reduction of the T-shaped or Y-shaped fractures which extend into the joint is far more difficult. A fixation bolt may be necessary to hold the condyles closely together. These fractures are always serious be-

cause of their effect upon the mechanics of the joint; exact anatomic reposition should be the aim, for they may give rise later to limitation of motion and traumatic arthritis.

Motion of the joint should be started as soon as feasible after reduction, approximately 6 to 8 weeks. On the other hand, weight bearing should be prevented for 3 months at least. There is danger that the soft callus will slowly "give" and permit slipping and alteration of the joint surfaces, which will give rise later to articular incongruities of the knee joint with marked instability.

Epiphyseal Fractures

Separation of the lower femoral epiphysis is usually seen between the ages of 8 to 17, although it may occur as the result of a severe accident any time before epiphyseal fusion. The epiphysis is displaced



FIGURE 333. Backward displacement of the lower femoral epiphysis. Note healed fracture of the posterior lip of the diaphysis.

forward occasionally, but usually backward, depending upon the injury. Often the epiphysis carries with it a wedge-shaped fragment of the diaphysis. This type of injury gives rise to all the signs and symptoms of fracture. Roentgenographic examination is essential (Fig. 333).

Because only a rather severe injury produces this displacement, it is accompanied by extensive soft tissue damage. There is always danger of injury to the popliteal vessels and nerves. Less frequently a separation and displacement of the upper tibial epiphysis may occur with or without fracture of the adjacent disphysis (Fig. 334).

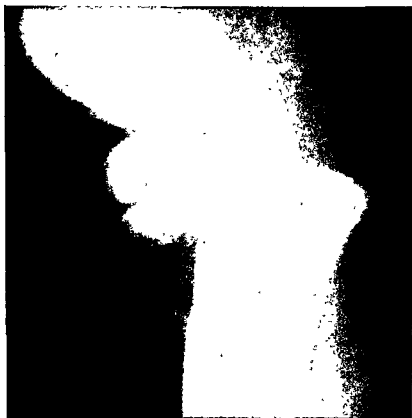


FIGURE 334. Fracture-dislocation of the upper tibial epiphysis

Treatment. Reduction can be accomplished under anesthesia in the acute cases by a manual method, placing the knee in as much flexion as the soft tissue swelling will allow. This permits the gastrocnemius muscles to relax and the quadriceps muscle to become tense and act as a splint, forcing the epiphysis into position. If the swelling is not severe, immobilization can be carried out with the knee kept in the flexed position for 6 weeks. Then the patient can begin active and passive movement and shortly thereafter weight bearing. With this fracture, however, gross deformity is fairly frequent and the epiphysis may have to be manipulated into position. If the fracture occurs early in childhood, growth may be interrupted, so that shortening, genu varum or genu valgum are complications

Patella Fractures

In fractures of the patella, usually caused by indirect force, the line of fracture may be transverse (Fig. 335) or longitudinal (Fig. 336); if the blow is direct, the fracture is apt to be fragmented and comminuted.

Occasionally one sees a *bipartite patella* — a congenital anomaly — which may be confused with the picture of an acute fracture, but in suspected cases a roentgenogram of the other knee should be taken.



FIGURE 335. Transverse fracture of the patella.

A careful study of the roentgenogram (Fig. 337) will show the edges of the suspected fracture to be smooth and regular, suggesting a congenital bipartite patella rather than a fracture.

Treatment. When there is a chip fracture of the patella without displacement, a posterior molded splint and guarded movement for a few weeks may be all that is necessary.

When a transverse fracture with separation occurs, an open operation and fixation of the fragments by means of fascia, wire, silkworm or chromic catgut will usually allow complete reduction and assure a good end result.



FIGURE 336. Longitudinal fracture of the patella. This type of fracture is often overlooked when only the routine anteroposterior and lateral views are seen.

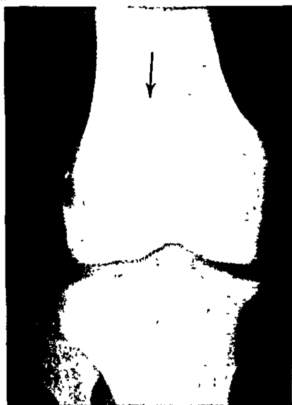


FIGURE 337. Bipartite patella. This is a congenital anomaly rather than a fracture.

In the severely comminuted type it is difficult to preserve the articulating surfaces of the patella by any operation. Occasionally a pursestring suture can be taken around the comminuted fragments, tying them snugly and thereby fitting the jigsaw puzzle together. In the presence of many comminuted fragments this frequently cannot be done, in which case complete removal of the patella has been advocated. Restoration of a very satisfactory degree of joint function may follow patellectomy.

In any open operation for a fresh fracture of the patella it is important to treat not only the bone fragments, but also the tear in the aponeurotic expansion of the quadriceps. Roentgenograms of a fractured patella show only the bone injury, whereas the soft tissue tear can cause more disability than the fracture. Its extent should be determined by gently washing out the joint with normal saline solution and then carefully suturing the torn lateral expansions.

When the articular surface of the patella can be closely approximated so that it heals smoothly a normally functioning knee results, but when irregularities on the articulating surface develop, subsequent pain and disability may be expected. Patellectomy is then frequently the treatment of choice, but if there is a large articulating fragment, excision of the small fragment only should be done.

Upper Tibial Fractures

Fractures of the upper extremity of the tibia just distal to the joint or entering into the joint, such as may be caused by a blow from a car bumper, have been called "bumper fractures." These may or may not be accompanied by a dislocation backward of the leg on the femur, depending upon the severity of the injury.

When the injury is a direct one to the outer aspect of the knee joint accompanied by forcible abduction of the leg on the thigh, the lateral tuberosity often fractures and is displaced downward; or vice versa, if the force is medially, it causes a depression of either the medial or lateral articulating tibial plateau (Fig. 338). Along with these plateau fractures are found considerable swelling with a definite change in the axis of the leg and thigh, marked instability of the knee joint, and frequently evidence of various other lesions such as injury to a cruciate ligament, tearing of the internal lateral or the external lateral ligament, or injury to the semilunar cartilage or cartilages.

Treatment. In the severe cases, after a roentgenogram is obtained, it is wise simply to aspirate the joint and permit the patient to have a

few days of elevation and immobilization in traction on a Braun frame before attempting any open surgery. If roentgenograms then show that the fragments have slipped into approximately their normal position, one should be content to continue with this treatment. Then after a

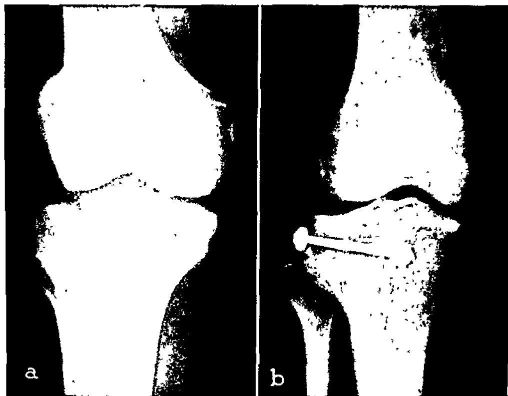


FIGURE 338. Plateau fracture of the tibia extending into the shaft (*a*). Restoration of the articular surface achieved by open reduction and bolt fixation (*b*).

few weeks plaster can be applied, and the patient allowed to be up on crutches. Weight bearing should not be permitted for at least 3 months after the injury and then only after roentgenograms show bony union.

Whenever there is gross displacement and closed reduction does not suffice, one may try compressing the fragments into place, i.e., applying to the condyles a wooden vise or manual pressure to replace the fragments. When this fails, open operation with replacement of the fragments into normal position and application of some type of internal fixation (Fig. 339b) is indicated. Also, definite damage to the meniscus requires its removal.

In cases with comminution and severe mashing or pulverizing of the bone throughout the site of the fracture, an open operation should be the last resort, provided a fair restoration can be obtained by molding

the fragments into position. The prognosis must be guarded, for there is usually some permanent impairment to bone and soft tissue.

Precautions. In all cases, early weight bearing is definitely contraindicated, and the average patient requires from 3 to 6 months without full weight bearing. Usually after 8 to 10 weeks the limb can be supported by a Thomas ring splint with footpiece extension which prevents a knock-knee or bowleg from developing while the bone is undergoing consolidation. The brace also relieves the joint from the stresses and strains of actual weight bearing.

Tibial Spine Fractures

Fractures of the tibial spines (Fig. 339) are frequently due to severe injuries and pull of the cruciate ligaments. If the displacement is



FIGURE 339. Fracture and displacement of the tibial spine.

minimal, immobilization of the knee in complete extension for 3 or 4 weeks is all that is necessary. If the fragment is large and is not reduced by extension, early open operation and replacement is indicated.

Anterior Tibial Tubercle Fractures

Separation of the anterior tibial tubercle may occur before the

epiphysis is fused; fracture at this point rarely occurs in adults. Under too vigorous manipulation of a stiff knee, however, an anterior tibial tubercle fracture may be produced, or the patellar ligament may be torn loose from its insertion and require repair.

DISLOCATIONS

Traumatic dislocation of the knee (Fig. 340) usually consists of a posterior displacement of the tibia on the femur, although the dislocation may be lateral, medial or anterior. A severe trauma is necessary



FIGURE 340. Traumatic posterior dislocation and rotation of the tibia on the femur.

to cause such a dislocation. It is accompanied by tearing of the soft tissues about the knee, including the cruciate ligaments, with often danger of rupture of the popliteal vessels or severe injury to the peroneal nerves.

Treatment. If no vessel or nerve has been injured and the dislocation is reduced promptly and properly supported, the degree of excellent functional result that may occur in spite of the damage to the

soft structures in and about the joint is surprising. This is due partly to the integrity of the extra-articular soft tissues, particularly the quadriceps muscle and the hamstrings. If reduced late, in the older patient the result as regards function is very poor, and in old unreduced dislocations, fusion of the joint is preferred. If the patient is a young adult with an old unreduced dislocation, arthroplasty should be considered.

Pellegrini-Stieda's Disease

Calcification of the tibial collateral ligament, the so-called Pellegrini-Stieda's disease, is a rare affection which occurs most often in the young adult. Trauma is generally the exciting cause and the deposits of cal-

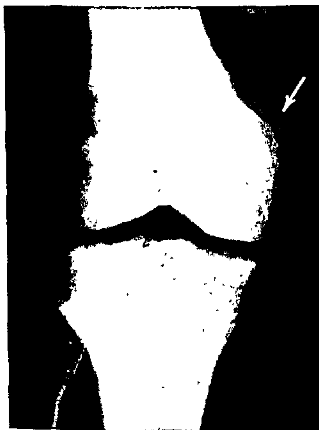


FIGURE 341. Pellegrini-Stieda's disease.

cium usually overlie the medial femoral condyle within the substance of the ligament. Local sensitiveness and pain on the extremes of motion, together with the roentgenographic findings (Fig. 341), make the diagnosis definite. The calcified areas can sometimes be palpated but many of these deposites disappear spontaneously without causing a long period of disability. If they continue to give symptoms, excision of

the abnormal calcified mass of bone and plastic repair of the ligaments become necessary.

Chondromalacia of Patella

Chondromalacia of the patella is produced by repeated trauma to the patella, when the articular surfaces of the patella and femur are crushed against one another. It presents gross changes suggestive of an osteoarthritis, ranging from fibrillation of its cartilage surface to frank degeneration. Areas of avascular necrosis may develop and resemble *osteochondritis dissecans* (see p. 534) — a condition found on the femoral cartilaginous surface.

Clinical Picture. Discomfort in the knee, especially on kneeling and climbing stairs, and a tendency for the knee to buckle and occasionally lock are the usual symptoms. Crepitus can be felt and often heard on movement and the pain is aggravated when the patella is pushed against the femur.

Roentgenographic findings are negative unless there is avascular necrosis. Roentgenograms should be taken in the anteroposterior view with the knee sharply flexed, showing the under surface of the patella.

Treatment. Rest and physical therapy may be tried. If the symptoms persist the joint should be opened and the patella partially removed or the shredlike cartilage shaved off close to the underlying bone.

Osgood-Schlatter's Disease (Epiphysitis of the Tibial Tubercle)

Osgood-Schlatter's disease occurs in adolescence. This is a disturbance of the tonguelike prolongation of the epiphysis of the tibial tuberosity which has not united to the underlying bone. Basically, glandular deficiency or avascular necrosis may be factors in its development, but usually direct trauma seems to initiate the disability. In childhood and adolescence this tongue of bone may be partly separated from the diaphysis by the pull of the quadriceps extensor muscle during exercise. The condition is usually unilateral, but may be bilateral.

Clinical Picture. The disease always gives rise to pain, local sensitiveness and enlargement and swelling over the anterior tubercle region, made worse by activity. Males are more frequently affected than females. The diagnosis should be confirmed by a roentgenogram; this shows a roughening of the tonguelike prolongation of the tibial epiphysis (Fig. 342). Sometimes fracture occurs with irregular

calcification of the tubercle. Roentgenograms of both knees should always be taken for comparison.

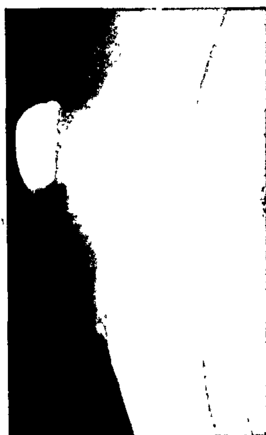


FIGURE 342. Osgood-Schlatter's disease.

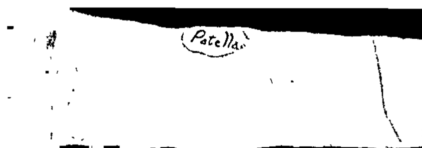


FIGURE 343. Knee strapping in Osgood-Schlatter's disease.

Treatment. In the majority of cases, simple fixation of the knee in the extended position by adhesive plaster (Fig. 343) or plaster splints lessens the pull of the quadriceps muscle and relieves the pain on walk-

of the joint and a roentgenogram at the operating table may disclose *hidden loose bodies and permit their removal before closing the* wound. With the diffuse type of osteochondromatosis a synovectomy, as complete as possible, is recommended.

Osteochondritis Dissecans

The typical finding in this joint affection consists of a dissecting type of osteochondritis and a localized semi-attached osteochondral body which has undergone a complete, or partial avascular necrosis.



FIGURE 345. Osteochondritis dissecans. The loose body is resting in its bed. (Walbach and Allison, *Arch. Surg.*, Vol. 16, p. 1179.)

It usually, but not always, lies on the under surface of the inner femoral condyle near the insertion of the posterior cruciate ligament (Fig. 345).

Etiology. One theory is that it represents the result of a thrombosis of the end arteries in this locality, induced by trauma, and producing a localized bone infarction The condition is also found in other joints besides the knee, especially the elbow, hip and ankle.

Clinical Picture. Occasionally "locking" of the joint with severe pain is seen when the fragment becomes loose and acts as a foreign body.

All cases do not progress to this stage and revascularization in the early case will occur if the joint is protected by a nonweight-bearing brace. When the mass is completely detached, arthrotomy and removal of the osteochondral body, plus curetting or drilling the crater-like cavity in the femoral condyle, is indicated.

TUMORS

Tumors of the synovial membrane are relatively uncommon, xanthomas being the most common. Synoviomas and hemangiomas are next in frequency (Chapter 16).

Xanthoma (Benign Synovioma)

Men are slightly more frequently affected than women. The solitary xanthoma, which is invariably pedunculated and attached to or near the medial meniscus, is the most common type. In the diffuse type, the entire synovial membrane is involved and shows yellowish discoloration. Eighty-five to 90 per cent of these tumors involve the knee joint, and it is stated that none to date have been reported occurring in the upper extremities (Fisher, 1933). These tumors are apparently related to some disturbance of the lipoid metabolism and contain the characteristic large rectangular foam cells.

An obscure chronic synovitis associated with intermittent pain and mild symptoms of mechanical block is suggestive of xanthoma. This is particularly so if an interarticular soft tissue swelling can be felt. As a rule the differential diagnosis clinically should consider loose body, giant-cell sarcoma, osteochondromatosis and chronic synovitis.

Roentgenographic examination is in many instances of little aid. Elevation of cholesterol in the aspirated joint fluid is pathognomonic; however, the color of the synovial fluid is not characteristic, as it is sometimes clear yellow and sometimes bloody.

Treatment. If the tumor is solitary, a simple excision of the tumor with a portion of its synovial base is preferred. In the multiple or diffuse type, a radical synovectomy is required.

No record of a benign giant-cell xanthoma undergoing malignant change has been reported.

Synovioma (Synovial Sarcoma)

Synovioma is a rare type of highly malignant tumor, arising from the periarticular soft tissues. It occurs chiefly in individuals under 30

years of age. The knee is the most frequent joint involved. There are no pathognomonic clinical features. An increasing pain in the knee is usual.

The tumor mass is found to be imperfectly circumscribed, invading the soft tissues of the joint, often perforating the adjacent bone and simulating a primary bone tumor. The definitive diagnosis is based on microscopic examination.

Treatment. Although patients have been reported remaining well as long as 9 years after local excision of the tumor, early amputation is indicated. The tumor is resistant to radiation.

Hemangioma

Hemangioma is a rare benign type of tumor of the synovial membrane, young adults being the most frequently affected. Rarely is the diagnosis made preoperatively. The presence of a boggy, thickened synovial membrane with a little increased local heat, and dilation of the superficial veins over the patella, accompanied by intermittent pain, is most suggestive of the diagnosis. Aspiration reveals bloody fluid.

Treatment. If the involvement is extensive, radiation therapy should be tried, but if the tumor appears to be well localized, wide local excision is indicated.

CONGENITAL DEFORMITIES

Dislocations of the Patella

Recurrent dislocation of the patella is unilateral or bilateral and occurs more frequently in females than in males. There may be an inherited tendency to congenital slipping of the patella, and this is often associated with a genu valgum and general muscle hypotonia. The patella almost always slips laterally (Fig. 346), occurring when the knee is partially flexed and the hip abducted.

Clinical Picture. When the dislocation is infrequent, the pain is very severe; in the chronic dislocated patella, the dislocation is usually followed by only moderate joint reaction, although the patient complains of a constant feeling of insecurity and some pain. Its sudden onset causes the patient to fall.

Treatment. In the acute traumatic type, simple reduction with adhesive strapping, holding the knee in extension with the patella pulled

toward the inner side, may suffice, although the swelling and acute tenderness is best treated by recumbency and cold local compresses.

In chronic recurrent patella dislocations, open operation is indicated. Various operative procedures have been devised. A sufficient degree of knock-knee or an abnormal flattening of the lateral femoral condyle

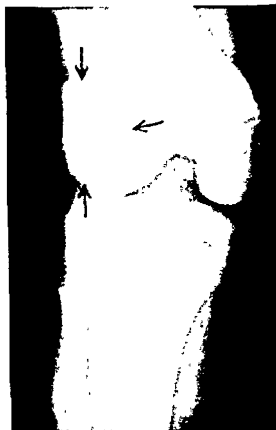


FIGURE 346. Patella displaced in a case of recurrent dislocation.

may be present to be a factor in producing the dislocation. If either of these anatomical abnormalities is severe they may themselves require preliminary correction.

Ordinarily a shifting of the patella medially can be achieved by removing a block of bone along with the patellar ligament from its normal insertion and transposing ligament and bone more medially and slightly downward into the medial surface of the tibia. A rectangular bony mass that has been removed to receive the transposed ligament can be replaced into the original patella ligament insertion (Chandler operation from Campbell, 1956).

It is very important when altering the pull of the transplanted ligament to see that a portion of the redundant capsule on the medial aspect of the knee joint is removed and inserted into the gap on the

lateral or contracted side and to bend the knee to a right angle on the operating table before closing the wound to avoid too much shortening of the transplanted patella ligament. The wound is then closed in layers and the knee immobilized in an extended position with plaster extending from the toes to the groin for 6 weeks. Then the cast is made bivalvular and physical therapy begun while the knee is slowly mobilized.

Congenital Genu Recurvatum

Congenital genu recurvatum, or extreme hyperextension of the knee, is rare, although occasionally it is so severe that the dorsum of the foot may touch the anterior surface of the thigh. This is more common than actual posterior displacement of the condyles of the femur on the tibia, although this congenital deformity does occur with the recurvatum. It is believed that malposition *in utero* causes the development of these deformities. Whenever a local congenital anomaly is observed, there are often other accompanying defects, so that the whole body should be examined. Commonly in persons with congenital deformities of the knees the patellae may be absent or very small, a spina bifida may be present, or occasionally a congenital dislocation of the hip or club foot may coexist. In these cases of congenital genu recurvatum, the quadriceps tendon, as well as the patellar ligament, is somewhat contracted and flexion of the knee is difficult. The acquired form of genu recurvatum is frequently seen in poliomyelitis (p. 654), when there is weakness or paralysis of the hamstring group of muscles and stretching of the posterior capsule of the joint.

Treatment. In infants with the congenital type of genu recurvatum, manipulation of the joint and stretching the contracted tissues on the anterior surface is the most efficient method of therapy, but it should be done gradually over many weeks. The knee can be brought into increasing flexion and stretched by repeated plaster casings. At times it is necessary to lengthen the contracted tissues on the anterior aspect, but usually nonoperative measures will suffice if the case is seen in infancy. In older patients operative intervention is necesary to gradually lengthen the contracted tissues.

Congenital Absence of the Patella

Congenital absence of the patella and even a *bipartite patella* are occasionally encountered; the latter condition may sometimes be mistaken for a fracture. Careful examination of the opposite knee and a roentgenogram of the bipartite patella will show a dissimilarity. The

site of the suspected fracture in the congenital lesion is smooth and possesses none of the characteristic features of the irregular edges seen in fresh fracture of the bone. Rarely does congenital absence of the patella necessitate surgery.

Congenital Malformation

Congenital malformation of the bones forming the knee joint may at times present very bizarre pictures; cases have been reported with a congenital absence of the knee joint and femur, the leg articulating with the hip, or with the whole lower extremity completely absent.

Congenital Contracture

Congenital contracture or *webbing of the soft structures on the posterior surface of the knee* is occasionally seen; this is characterized by inability to obtain complete extension. Sometimes a broad band of thickened tissue occurs in the popliteal region, such as seen in arthrogryposis. Without operation in these cases full extension cannot be obtained, although in many cases gradual stretching of the contracted tissues will suffice.

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12

The Leg

APPLIED ANATOMY

The tibia, the larger of the two bones of the leg, bears nearly all of the weight of the body. It articulates with the femur above and the astragalus (talus) below. Its fellow, the fibula, lies on a plane slightly posterior to the tibia and to its outer side. The two leg bones (Fig. 347) are firmly bound together by the interosseous membrane, and into these three structures the flexors and extensors of the knee insert, and from these the extrinsic muscles which move the foot arise. It should be noted that the head of the fibula is on a level with the anterior tubercle of the tibia The biceps tendon is inserted into the head of the fibula and the external popliteal (peroneal) nerve runs closely along the posterior border of this tendon. The peroneal nerve must be identified and carefully retracted whenever surgery is undertaken in this region. The nerve may also be injured in traumatic lesions to the external surface of the knee.

The tibia is triangular-shaped in its upper two-thirds, its internal surface is broad above, and the anterior border is subcutaneous throughout its length so that the crest of the tibia (shin) is easily injured. The posterior surface is covered by a thick group of muscles, and between the external tibial surface and the fibula are located the long extensor muscles of the toes

The head of the fibula is subcutaneous, but the lateral surface of the shaft is thickly covered by the peronei muscles, and the bone does not again become subcutaneous until the lower one-third of its length.

Muscles. The flexor and extensor muscles that move the foot and toes balance each other normally although the posterior group is much

stronger than the anterior. The dorsiflexors of the foot are the tibialis anterior, extensor digitorum longus and extensor hallucis longus muscles; those muscles that produce plantar flexion are the tibialis posterior, peroneus longus, peroneus brevis, flexor digitorum longus, flexor

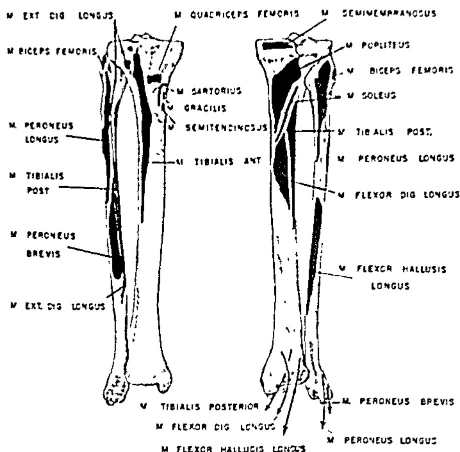


FIGURE 347. Bones of the leg showing muscle attachments. Red: muscle origin. Blue: muscle insertion.

hallucis longus, gastrocnemius and soleus. The inverters (adductors) are the anterior and posterior tibialis muscles, and the muscles that produce eversion (abduction) are the peroneus longus and peroneus brevis. The calf muscles are the gastrocnemius, soleus and the little plantaris; these give the "push" to the foot. Without this action, the individual would walk awkwardly on the heel, with the so-called "heel gait." These muscles are very powerful and compensate for the greater length of the foot being anterior to the center of motion at the ankle.

The deep fascia of the leg encloses the muscular bundles and sends two bands from its under surface, separating the abductor or peroneal group from the calf group posteriorly. The deep fascia is a dense enve-

lope, being continued at the ankle through the annular ligament; it is attached above to the tubercle of the tibia and the head of the fibula. The muscles of the leg largely arise from the bones of the leg and the interosseous membrane, but some of their fibers arise from this deep fascia.

Blood Supply. The leg is supplied by the anterior and posterior tibial and peroneal arteries. The superficial veins are the internal and external saphenous; the deep veins accompany the arteries (venae comites). These deep veins all have valves and are frequently in communication with the superficial veins; thus when there is an obstruction the valves may become ineffective and a tortuous, wormlike venous mass (varicose veins) develops in the superficial veins; if they or the deep veins become infected a phlebitis develops.

Nerve Supply. The tibial (internal popiteal) nerve, formed by fibers from the anterior branches of the fourth and fifth lumbar and the first, second and third sacral nerves, lies to the inner side of the posterior tibial artery as it descends the leg. Soon it becomes more superficial and then descends the leg to the outer side of the artery, maintaining a continuous external relation to that vessel as far as the ankle, where it divides midway between the internal malleolus and the posterior tuberosity of the os calcis into the internal (medial) and external (lateral) plantar branches which go to the foot. It gives off branches, both in the popliteal space and below, called articular, cutaneous and muscular branches.

The common peroneal (external popliteal) nerve, the other branch of the great sciatic, passes behind the external condyle of the femur and runs just below the head of the fibula, going into the substance of the peroneus longus muscle, and then dividing into terminal branches of the deep peroneal (anterior tibial) and the superficial peroneal (musculocutaneous) nerves. The anterior tibial continues down the leg, lying close to the anterior tibial artery along its entire course in the leg, and then accompanies the dorsalis pedis artery on to the dorsum of the foot, supplying muscular branches in the leg to the anterior tibial, the extensor digitorum longus, the extensor hallucis longus and peroneus tertius muscles. Paralysis of these muscles results in "foot drop." The muculocutaneous nerve passes downward in the fibers of the peronus longus muscle to lie between the two peronei muscles and the extensor digitorum longus, and runs down on the dorsum of the foot to be distributed to the cutaneous surface. Its muscular branches supply the peroneus longus and peroneus brevis.

DISEASES

Tuberculosis

Tuberculosis of the long bones involving the shaft is rare. It is a chronic disease, and when it occurs the tibia or femur is most frequently affected. Usually it is seen in patients over 20 years of age and is associated with active pulmonary or other tuberculous lesions. Curettage or saucerization with immediate skin closure is preceded and followed by administration of streptomycin (see Chapter 2, page 53).

Osteomyelitis

Among the nontuberculous diseases of the long bones are those which give rise to an *acute osteomyelitis*. The disease may be localized to one part of a bone but often spreads through the entire shaft. The infection may be produced by such organisms as a pyogenic bacterium, a fungus, a parasite or a spirillum. It usually originates in the metaphyseal region of a bone. The organism may enter the tissues either from without, from lacerations or compound fractures (exogenous osteomyelitis), or it may arise as a blood-borne infection from some distant focus (hematogenous or endogenous osteomyelitis) (Chapter 2).

Hematogenous osteomyelitis of the tibia or fibula is not common today and usually the disease can be controlled by the suitable antibiotic. However, a red, swollen, tender area appearing in the leg always suggests impending danger. A patient with these symptoms should be hospitalized and adequate rest and splinting employed, accompanied by doses of the selected antibiotic. If a fluctuant area develops, aspiration can be helpful in deciding the organism responsible. Whenever the infection is not rapidly brought under control by antibiotics, small frequent blood transfusions should be given; even incision and drainage are justified to vigorously combat the infection. Procrastination until massive bone destruction is evident by roentgenogram (Fig. 348) is fortunately rarely seen today. If osteomyelitis is confined to the fibular shaft, excision of this bone is later desirable.

Brodie's Abscess. A form of chronic osteomyelitis frequently found in the tibia is the so-called Brodie's abscess, which is a localized form of bone infection caused by an organism of low virulence, or one that has become attenuated. The common site of infection is the lower end of the tibia. A thin wall of fibrous tissue and sclerotic bone will form



FIGURE 348. Acute osteomyelitis in the upper end of the tibia. Bone destruction is characteristic.



FIGURE 349. Brodie's abscess in lower end of tibial diaphysis. The linear periosteal accretions indicate recent reactivity. (Brailsford, *The Radiology of Bones and Joints*, J. & A. Churchill, Ltd.)

about a sterile abscess in the bone cavity. The symptoms can be very mild, the most characteristic one being pain, often worse at night, associated with slight tenderness over the site of the lesion, and occasionally an increase in local heat. These clinical signs, along with a roentgenogram (Fig. 349) showing a single punched-out, definitely circumscribed area perforating the cancellous bone at about ½ inch from the ankle joint, are characteristic of a Brodie's abscess. Treatment consists in curetting the cyst wall and saucerizing the bone so that the bony walls are sloping and not perpendicular.

Sclerosing Osteitis of Garré

The condition called a chronic diffuse "sclerosing osteitis of Garré" occurs in late childhood, more frequently in boys than in girls, and



FIGURE 350. Sclerosing osteitis of Garré.

involves particularly the tibia. It gives rise to a spindle-shaped enlargement of the bone and is accompanied by pain and local tenderness embracing approximately the middle two-thirds of the shaft. There is rarely pus formation but an increased thickening and density of the cortex may be seen by roentgenogram (Fig. 350). It may sometimes

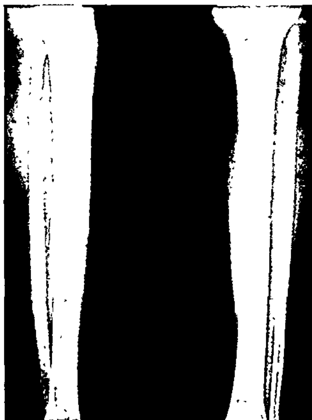


FIGURE 351. Luetic periostitis.

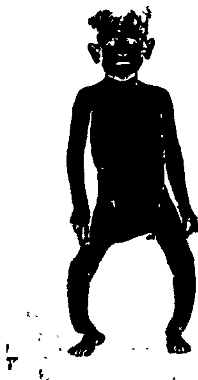


FIGURE 352. Severe double bowlegs. Correction required multiple osteotomies.

be difficult to distinguish this disease by roentgenogram from eosinophilic granuloma, syphilis, osteoid osteoma or Ewing's sarcoma, all of which are discussed under Bone Tumors (Chapter 16).

Treatment consists in saucerizing the thickened cortex, though occasionally recurrence of the pain and bone sclerosis follow this treatment and reoperation is necessary.

Syphilis

Syphilis of the bones may be either of congenital or acquired form and the tibiae are frequently involved. Proper antisyphilitic therapy should be instituted. Roentgenographically, marked periosteal thickening is characteristic (Fig. 351). Compare Figures 350 and 351.

Rachitic Deformities

Under the age of 3, bowlegs (Fig. 352) or knock-knees can usually be corrected by braces. After this age the bones are so hard that osteotomies are usually necessary.

SOFT TISSUE INJURIES

Muscle Tears

Contusions to the leg are very common injuries in athletes. The gastrocnemius, the plantaris and the peronei are the most frequently injured leg muscles.

Occasionally incomplete rupture of the *Achilles tendon* may occur, giving rise to local swelling, tenderness and diminished power of plantar flexion to the foot. If there is definite evidence of a complete rupture of the Achilles tendon, the rupture should be treated by immediate operation and suture with fascial strips. Usually, however, there is an incomplete division so that rest and adhesive strapping, or preferably a plaster boot, with the foot in equinus position will be required for 6 to 8 weeks.

Rupture of the *small plantaris muscle* may also occur, giving rise to local tenderness along its course; this fairly common injury may be produced by a sudden pull as in jumping or by unusual strain on the calf group. Swelling of the calf with extensive discoloration of the skin over the muscular course of the plantaris is characteristic. The belly of this little muscle passes downward and inward from the external condyle of the femur between the gastrocnemius and soleus, and terminates in a long tendon inserted into the posterior tuberosity of the

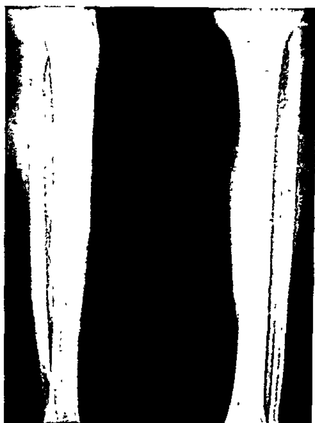


FIGURE 351. Luetic periostitis.

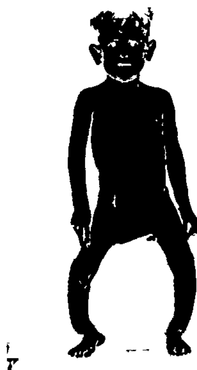


FIGURE 352. Severe double bowlegs. Correction required multiple osteotomies.

(2) When there is an oblique type of simple fracture of one or ...oth bones the treatment is different. (*a*) Insertion of Kirschner wires ...r two Steinmann pins well above and below the fracture site permits



FIGURE 353. Transverse fractures of fibula and tibia.

the fracture to be reduced under the fluoroscope. The wires and limb are then encased in plaster. This has the advantage of application of the plaster only to the knee, allowing this joint to be mobilized early. (*b*) Another method, which requires longer hospitalizaton, is the use of the Braun frame with traction placed through the os calcis (Fig. 354), but when the fracture is oblique accurate reduction is difficult to maintain. (*c*) Adequate treatment in the oblique fracture (Fig. 355), therefore, often means an open operation and the insertion of one or more transfixion screws with or without a plate or bone graft, depending on the degree of fixation obtained by the transfixion screw alone.

Complete immobilization is necessary for at least 8 weeks following these fractures and, if roentgenographic evidence shows that union is then delayed, further plaster immobilization should be continued. When the plaster is removed an adequate brace should be worn for several months thereafter.

os calcis or merges into the side of the Achilles tendon. Rest and strapping and bandaging (see Fig. 367) the foot in slight equinus will usually relieve the patient; usually 3 to 4 weeks of treatment is required.

In athletes, the tearing of a few of the *tibialis posticus muscle* fibers from the tibia in its lower third may result from running on a hard surface. Heat, massage and strapping, with rest and support of the foot in the inverted attitude, are usually sufficient to relieve the pain.

FRACTURES

A fresh fracture needs immediate immobilization, and as soon as possible roentgenograms must be taken in at least two planes, and frequently more. A roentgenogram of the entire leg including the joints above and below the site of fracture should always be made to avoid overlooking an accompanying fracture of the fibula and to note the alignment of the joint surface above and below the fracture site.

Shaft Fractures of Both Leg Bones

Fractures in the shaft of the tibia and fibula may occur by both direct and indirect violence. When the leg is struck *directly* the fracture is often transverse in type with or without comminution of the bone (bumper fracture). In this type of injury both bones may be broken at approximately the same level (Fig. 353). With an *indirect* blow a spiral fracture of the tibia with or without comminution usually results, combined with a fracture of the fibula at a somewhat higher level. A twisting maneuver such as occurs in skiing is a common cause.

Clinical Picture. The gross appearance of the leg is sufficient to make the diagnosis, but crepitus, deformity and false motion can easily be demonstrated As these fractures are usually the result of severe violence, there is extensive soft tissue damage with considerable bleeding within the tissues. These fractures are always serious, and nonunion or delayed union of the tibia often occurs when in the lower third of the leg.

Treatment. (1) When tibial and fibular fractures are simple and transverse, manipulation and closed reduction of the tibia under an anesthetic with immobilization in plaster, extending from the toes to above the slightly flexed knee, will be adequate, provided the displacement can be corrected. The plaster should be worn for 10 weeks at a minimum. Roentgenograms will usually disclose when the union is sufficient to discard support.

Prognosis. In a fresh fracture in a child or young adult the prognosis is very good when the patient is seen early and the fracture is accurately reduced and immobilized. In older individuals, and particularly in those with fracture in the lower third of the tibia, the prognosis is not good for bony union. Roentgenograms are the best criterion for the degree of bone healing.

Fibular Shaft Fracture

Stress fracture of the lower shaft of the fibula is common in athletes. As pointed out by Devas and Sweetnam (1956), the onset may be abrupt or insidious, the latter being the more usual. Local tenderness behind the ankle and swelling at the site of the fibular shaft fracture following running on a hard surface was the finding in most of the cases. Burrows (1948) recorded 24 stress fractures scattered throughout the length of the fibula, the majority occurring in the upper third. An oblique view of the fibular shaft must be taken if routine roentgenographic views do not disclose the fracture.

Treatment. If unrecognized, pain and disability may be prolonged for 3 to 6 months, but with immediate rest and proper treatment the symptoms subside in a matter of a few weeks. A carefully applied Gibney strapping is usually applied and moderate activity is desirable. Rarely is a plaster boot necessary. In fact in the athletic age period, such complete immobilization delays the return of normal function.

In those fractures about the head of the fibula injury to the peroneal nerve should always be looked for, i.e., inability to actively dorsiflex the foot.

Delayed Union and Nonunion

When frank nonunion occurs, and the lower third of the tibial shaft is a favorite site, several methods of treatment must be considered: (1) An operation must be done to remove the dense scar tissue between the bone ends in order to approximate the bones closely and to stimulate vascularity. At the same time the application of a massive bone graft, fixed by four screws (Fig. 356), with cancellous bone packed about the fractured surfaces, offers an excellent opportunity for bony union of the tibia to occur. The fibula is rarely the seat of nonunion.

(2) In the case with only delayed union, further immobilization may be obtained by the use of the walking plaster boot (Fig. 357). This may be combined with multiple drilling of the bone at the site of the

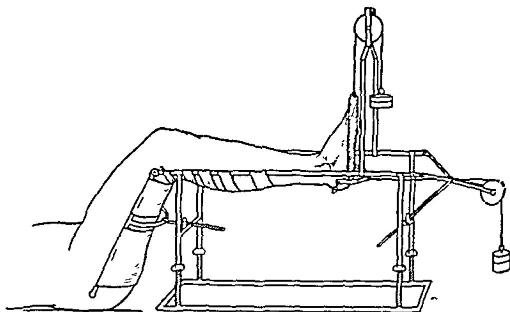


FIGURE 354. Braun frame, with skeletal traction through the os calcis.

FIGURE 355. *Left,* oblique fracture of the tibia. *Right,* treatment by open reduction and screw fixation. Note the necessity for roentgenograms of the entire leg if both low tibial and high fibular fractures are to be recognized. The shaft torsion will not be revealed unless the joints above and below the fracture are included.

delayed union to stimulate osteogenesis. (3) If weight bearing is not feasible, the use of Mommsen's method of submaximal stimulation (Krida, 1930) may be employed. The apparatus shown (Fig. 358) is incorporated into the plaster boot, a window being cut out over the



FIGURE 358. Mommsen apparatus, useful in cases of delayed healing of tibial fracture. The patient can repeatedly strike the padded hammer against the thickened skin of the heel.

heel; the patient applies the hammer blow, 5 to 10 minutes every hour, by a rope. The patient pulls the hammer upward and allows it to fall, striking the heel.

CONGENITAL DEFORMITIES

Under this term can be recognized several main types of congenital origin.

Anterior Bowing

Congenital Absence of the Fibula. This condition is associated with a fixed equinovalgus deformity. The affected leg is shorter than its fellow. The tibia is often bent sharply forward (Fig. 359). At the apex of the deformity the skin may be adherent or may present a dimpled appearance. The foot has a characteristic pattern, usually consisting of equinovalgus and absence of the two outer toes and the corresponding metatarsal bones.

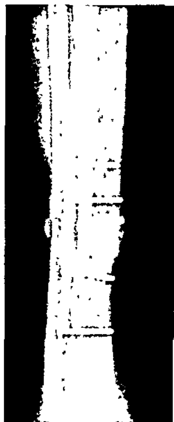


FIGURE 356. Massive bone graft *in situ* following operation for tibial nonunion.

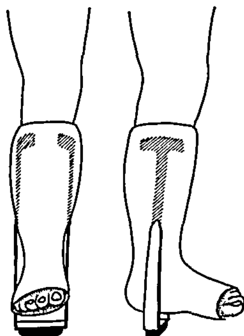


FIGURE 357 Walking plaster boot Walking iron inserted into the plaster, if properly applied, allows most of the weight to be transmitted to the condyles of the tibia This requires the careful application of the plaster, which is molded to the leg contour.

of conditions, the percentage of bony union is not above 75 per cent. In the cases in which repeated bone graft operations have failed, amputation has sometimes been necessary. The introduction of the de-



FIGURE 360. Congenital pseudarthrosis, showing characteristic deformity.

layed bone graft method of Moore (1949) has improved the prognosis for bony union. In this method the graft is separated from its bed and then replaced *in situ*. A few weeks later it is removed and placed at the site of the nonunion, thereby stimulating an increase in osteogenesis. Another method is the two stage fibula transplantation by Wilson (1941).

Posterior Angulation of the Tibia

Posterior angulation of the tibia with shortening at the junction of the middle and lower thirds of the diaphysis is an extremely rare congenital anomaly. Heyman and Herndon (1949) have reported 3 cases and Heyman personally has since seen a dozen more cases. It is worthy of mention because of the good prognosis. This is in marked contrast to the anterior congenital bowing deformities. It is not believed to be due to a primary germ defect or any underlying fibrocystic bone lesion.



FIGURE 359. Congenital absence of the fibula with the typical deformity of the tibia and foot.

Treatment consists in correction of the deformity as much as possible, although the function of the foot is permanently impaired to some degree. Bowing of the tibia is corrected by osteoclasis or osteotomy, and later a leg brace can be prescribed. If treatment is not instituted until the patient has passed the period of infancy but is still in early childhood, astragalectomy and placement of the foot backward underneath the leg, after the tibial bowing has been corrected, will give a fairly stable weight-bearing extremity. In adult life sometimes amputation through the lower third of the leg may be the method of choice.

Congenital Pseudarthrosis. This rare condition is characterized by fracture of one or usually both bones of the leg shortly before or shortly after birth (Colonna, 1934). This type of fracture (Fig. 360) is peculiar in that a pseudarthrosis with anterior angulation develops at the site of fracture. Some persons believe that there is a pre-existing cyst in the bone which predisposes it to fracture (Kite, 1941), whereas others believe that there is a congenital atresia of the blood vessels supplying the area affected or a basic morphologic defect. Although the affection may be found in other bones such as the clavicle, it is most common in the leg bones. Following the fracture, anterior bowing occurs and a well-developed false joint may be found at operation at the site of the fracture.

It is very difficult to achieve bony union in treating this condition. Conservative measures always fail to produce union. Operation upon very young patients is not indicated After the child has passed the age of 5 years, a dual bone graft operation such as described by Boyd (1941) should be tried, although in young children, under the best

The muscles are not resistent to stretching and the roentgenogram (Fig. 361) simply reveals an increasing thickness of the tibial cortex on the concave side of the curve with the fibula similarly bowed. There may or may not be a dimple on the skin at the apex of the angulation.

The treatment is conservative, and the results show that surgical correction of the bowing is not necessary. Massage and stretching of the soft parts and wearing a well-fitting long Thomas ring splint, with adjustable leather cuff at the apex of the curve and a stop-joint at the ankle to prevent calcaneus, allow the curve to be gradually corrected. The brace should be applied as soon as the condition is recognized. According to Heyman, in selected cases an epiphyseal arrest on the sound side has been worthwhile.

Intrauterine Amputation and Constrictions of the Leg

Intrauterine amputations or constrictions of a limb (Fig. 362) are occasionally seen. These are due to abnormal development of the germ

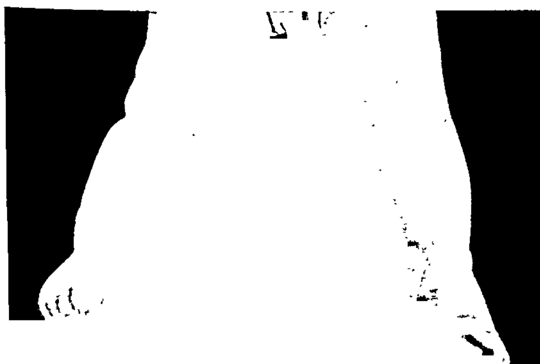


FIGURE 362. Congenital constricting bands in the right leg.

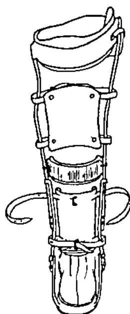
plasm and are probably congenital changes produced by mesenchymal defects. The constriction is characterized by a deep circular fold about the arm or leg. These dense fibrous bands may cause a deep creasing of the tissues. In the mild type of deformity no treatment is required,

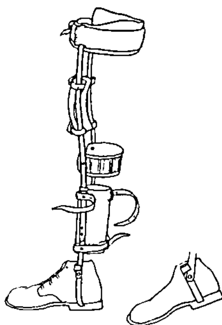


A



B





C

FIGURE 361. (*A*) Posterior angulation of tibia in 8-month-old child, before treatment. (*B*) Same patient 5 years later. (*C*) The brace used in the treatment of posterior angulation of the tibia with talipes calcaneus. (Courtesy of Clarence H. Heyman, M D.)

13

The Ankle

APPLIED ANATOMY

The ankle joint proper is a hinge joint of the mortise and tenon variety which is formed by the lower extremity of the tibia and the fibula and the upper articulating surface of the talus (astragalus), which is the only bone in the lower extremity without muscle attachments. A synovial membrane lines the joint. The capsule surrounding the joint is thickened on the inner and outer side, thereby greatly protecting the joint against injury. On the inner side, the thickened portion of the capsule is fan-shaped (the deltoid ligament), running from the tip of the internal malleolus in three directions, forward, downward and backward, inserting into the scaphoid, calcaneus and astragalus respectively. The external lateral ligament also is composed of three bands, all of which arise from the tip of the external malleolus and pass both forward and downward to insert into the astragalus and calcaneus respectively. One or all of these bands are frequently torn in a sprain of the ankle. The joint bears the weight of the entire body at each step and its integrity depends not only upon the mortise character of its bones, but also upon the strong internal, external and interosseous ligaments as well as the tendons of the muscles surrounding it. The time of the appearance of the epiphyses and their approximate fusion dates are shown in Figure 363.

In addition to capsular structures, the joint is strengthened behind by the Achilles tendon; anteriorly by the common extensor and exensor longus hallucis muscles; antero-internally by the tibialis anticus (tibialio anterior) muscle; postero-internally by the tibialis posticus (tibialis posterior) muscle; and externally by the peroneus longus and peroneus brevis muscles.

but if the condition interferes with the nutrition of the part, or if for cosmetic reasons correction is desired, the constriction band of scarlike tissue is carefully dissected out and the adjacent tissues are approximated. The operation should be upon only one half of the constriction at one time whenever the folds are deeply creased.

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of muscles. Dorsiflexion can be accomplished 10 to 20 degrees less than a right angle and is accomplished by the anterior tibial muscle and common extensors of the toes plus the extensor hallucis longus muscle. Inversion is accomplished by the anterior and posterior tibials



FIGURE 364. Normal range of ankle motion. Dorsal and plantar flexion (*A*); eversion and inversion (*B*).

and eversion by the peroneus longus and brevis muscles. Adduction, or the turning of the foot inward in its relation to the leg, and its reverse motion, abduction, for all practical purposes are regarded as synonymous terms for inversion and eversion respectively, or for pronation and supination.

DISEASES

Tuberculosis

Tuberculosis is found less frequently in the ankle than in the spine or the knee and is very rare in children. The joint becomes infected by secondary extension. It is usually osseous rather than synovial in origin. Because the joint is surrounded by tendons rather than muscle tissue, abscess formation is more apparent than in many of the other

The ankle joint proper has principally two movements, flexion and extension, although with the toe pointing sharply downward there is a slight degree of lateral movement.

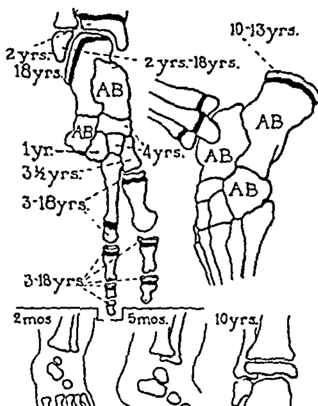


FIGURE 363. Time of appearance and fusion of the epiphyses at the foot and ankle. AB: at birth.

The mortise of the ankle joint is a very important structure. It is made up of the tibia and fibula which are firmly bound together by dense ligaments. Widening of this mortise frequently occurs following severe injuries to the ankle joint area.

EXAMINATION

The primary movements of the ankle and foot are dorsiflexion, plantar flexion, adduction and abduction (Fig. 364). Although simple plantar flexion and dorsiflexion are confined to the ankle joint proper, the movements of abduction (eversion) and adduction (inversion) occur in the subastragalar joint; adduction and abduction to a slight degree are also carried out in the midtarsal joints.

Plantar flexion can be normally accomplished 50 to 60 degrees more than a right angle and is produced by the contraction of the calf group

In the young child, a tuberculin test may be of some value in deciding the diagnosis, or if there is abscess formation, aspiration and injection of the fluid obtained into a guinea pig for culture is recommended.

Roentgenographic Findings. The early stages present bone atrophy and soft tissue swelling; later, when bone destruction has occurred, the site of the bone lesion can be demarcated. The absence of bone proliferation is characteristic.

Treatment. If the case is seen early and the disease is limited to one bone in the foot, such as the astragalus, excision can result in complete eradication of the bony focus; an astragalectomy is advised in adults and children in such cases.

Statistically it has been shown that tuberculosis of the ankle joint has a tendency to metastasize to other parts of the body, and delay of treatment may jeopardize the life of the patient.

Children. Immobilization of the joint and complete rest in a light plaster boot extending from the toes to the knee with the foot supported at right angles and in a neutral attitude may give rise to a fibrous or bony ankylosis of the joint. Various types of braces may be applied, but use of plaster support is most satisfactory to correct gradually the deformity that has developed through the spastic muscle pull, as well as to supply immobilization.

All tuberculosis is evidence of a generalized disease; the proper constitutional treatment should consist of rest, adequate diet and streptomycin, along with efforts to prevent local deformity. Conservative treatment of rest and support should be employed in children for many years before definitive treatment such as an arthrodesis should be done. In children, amputation is rarely indicated, but a long-continued course of antibiotic therapy is indicated.

Adults. In the adult with multiple draining sinuses and marked bone destruction the economic time factor is such that financially and economically the patient is frequently better off with an early amputation. This should be done at the site of election, about 7 inches below the knee. The patient can then be fitted with a satisfactory type of prosthesis; this is a distinctly preferable method of treatment for the wage-earning type of adult patient.

In adults who have no abscesses or draining sinuses and in whom tuberculosis involving the joint has been discovered early, a surgical fusion of the joint will result in a stable, painless, weight-bearing extremity. In men the joint is usually fused with the foot in 95 to 100 degrees equinus, in women 105 to 110 degrees in order to permit

joints. The primary focus of disease may be in the internal or external malleolus or both, but in the large majority of cases it appears to be the astragalus that is primarily involved. For the pathologic picture see Chapter 2.

Clinical Picture. The history of a minor injury preceding the onset can usually be obtained. A chronic, painful disease of the joint in which motion is limited by muscle spasm and in which there is a tendency for the joint to become progressively deformed presents the characteristic picture of tuberculosis. A slight limp with pain on weight bearing is an early sign, and swelling of the soft tissues behind the malleoli and in front of the Achilles tendon is frequently found on examination. Early in the disease the patient presents local heat and redness of the ankle and a tendency to walk on the heel with the foot inverted. This condition may be confused with a sprain or other soft tissue injury, but the history of onset and the fact that the pain is persistent when the part is not in use, particularly at night, is strongly in favor of a diagnosis of tuberculosis. Early in the disease the patient may assume the heel-gait method of walking, due to the underlying tuberculosis, but erosion and destruction of the joint surface plus muscle spasm soon leaves the foot in an attitude of equinus. Depending upon the extent and exact portion of the joint involved, the foot later assumes an equinovarus or equinovalgus attitude. Frequently the growth of the foot becomes much retarded. Multiple sinuses (Fig. 365) are present when the disease is of long standing, and in these cases the prognosis is poor.



FIGURE 365. Advanced tuberculosis of the ankle joint. Note sinuses.

In the young child, a tuberculin test may be of some value in deciding the diagnosis, or if there is abscess formation, aspiration and injection of the fluid obtained into a guinea pig for culture is recommended.

Roentgenographic Findings. The early stages present bone atrophy and soft tissue swelling; later, when bone destruction has occurred, the site of the bone lesion can be demarcated. The absence of bone proliferation is characteristic.

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a higher heel to be worn. In fusion of this joint many of the adjacent small joints in the foot will permit a certain amount of compensatory movement, so that the patient often walks with a barely perceptible limp. *Preoperative and postoperative antibiotic therapy is indicated.*

Nontuberculous Arthritis

This may be caused by the staphylococcus, gonococcus, or occasionally by other types of organisms. Acute osteomyelitis of the lower end of the tibia or fibula may spread into the ankle joint causing a pyarthrosis, and although it can arise primarily in the joint, it is usually an extension process. Articular involvement occurs in the course of many other infectious diseases, notably, scarlatina, pneumonia and typhoid fever.

Pathology. See Chapter 2.

Clinical Picture. The symptoms of redness, local heat, muscle spasm, pain on any movement and swelling of the ankle joint are all evidences of an acute arthritis. If the joint cavity is swollen or pus is suspected, aspiration or incision and drainage of the joint is necessary.

Treatment. Heavy continued doses of penicillin or the appropriate antibiotic, when wound culture is available, should be started as soon as possible.

The patient is most comfortable when the limb is immobilized in plaster. A natural joint fusion may occur; if not, surgical fusion must be done, using a sliding bone graft from the tibial shaft after the disease is quiescent.

Gonorrheal Arthritis. The so-called gonorrheal rheumatism or gonorrheal arthritis (p. 64) complicates a large majority of all cases of gonorrhea, the joint complication occurring shortly after the original infection. It is estimated that about 16 per cent of all gonorrheal arthritis involves the ankle joint.

The gonorrhea can be treated most successfully with penicillin, while the joint can best be treated by immobilizing it with a plaster extending from the toes to the knee.

SOFT TISSUE INJURIES

Sprains

A sprain is a rupture of the ligamentous fibers surrounding a joint.

The ankle is the joint most commonly sprained. The calcaneofibular and the anterior inferior tibiofibular ligaments are often torn (1) by a

sudden, sharp turning inward of the foot caused by a misstep, (2) by chronic ligamentous relaxation and (3) by a poorly balanced foot.

Examination. In any suspected sprain of the ankle a routine gentle examination of the possible active and passive movements should be made, as well as observing the localized swelling and tenderness. The bony prominences must be examined for localized bone tenderness to rule out the possibility of fracture or dislocation, and the ligaments must be individually tested since it is easy to ascertain how many and which ligaments are involved in the sprain. After localizing the injury accurately, treatment can be more intelligently applied.

Roentgenographic Findings. When it is difficult to estimate with accuracy the severity or degree of the soft tissue injury, roentgenograms should be taken. Particular attention must be given regarding a widened mortise of the ankle joint which will give rise, if uncorrected, to a permanently weakened ankle. Roentgenogram may show a small chip fracture combined with the sprain, which can definitely lengthen the period of disability. In cases in which there is clinical evidence but no obvious roentgenographic appearance of a fracture, it is wise to get oblique views as well as anteroposterior and lateral views of both ankles in the same planes.

Treatment. If a sprain is uncomplicated by fracture, one may partly reduce the effusion by gentle massage, after which the foot may be strapped with a Gibney strapping (Fig. 366). Another method that has proved successful in sprains uncomplicated by fracture is the local application of ethyl chloride spray to the tender points. Application of this spray renders the area anesthetic, but it may be necessary to repeat the treatment several times. The patient may then be able to walk painlessly on a flat surface. Controlled activity is always of value in reducing effusion. With a simple ankle sprain it is not necessary to immobilize the foot and leg in a plaster casing, for it defeats the purpose of early active motion, but a Gibney strapping is useful.

If the sprain is complicated by a chip fracture, it is wise to employ a light plaster casing and to warn the patient that a longer period of disability will ensue. Essentially the treatment of early active motion and a longer period of protection from weight bearing is to be followed.

To avoid a repetition of ankle sprain after an acute injury, it is wise to search for any underlying cause of foot imbalance before the patient is discharged. Many times simply a properly fitting shoe with a Thomas heel will protect the patient from a re-sprain.

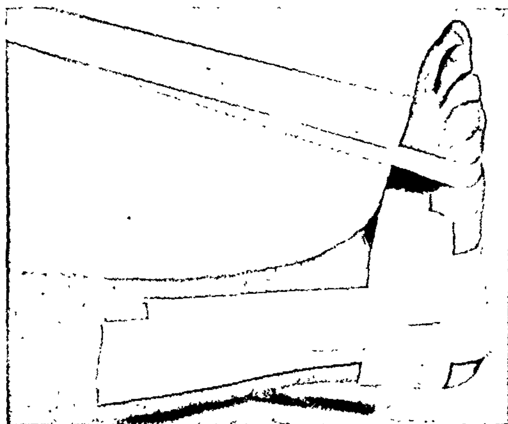


Figure 366. Gibney strapping. While strapping is being applied, the foot is held at a right angle midway between eversion and inversion. Several more crisscross strips should be applied than are shown. Never completely encircle the foot or leg with the strapping.

Tenosynovitis

Tenosynovitis (peritendinitis, or peritendinitis crepitans) is characterized by noticeable swelling in the region of the insertion of any of the tendons but especially of the Achilles tendon into the os calcis, and is accompanied by crepitation on motion that is unmistalable. It is usually marked by local tenderness with considerable pain on resistive movement.

Treatment. Rest and application of heat or diathermy to the tender area are most important. If it is necessary for the patient to walk, it can be done more easily (1) by inserting a soft felt heel into the shoe to lessen the excursion of the Achilles tendon in walking, (2) by strapping the foot and ankle to avoid the muscle pull on the affected tendon and (3) by the injection of 1 to 2 cc. of Hydrocortone into the affected tendon sheath.

Achillobursitis

Achillobursitis is a localized inflammation of the bursa lying on the

posterior surface of the os calcis near the insertion of the Achilles tendon. It becomes enlarged and sensitive. If very acute, local heat and elevation of the leg with complete rest from weight bearing may be necessary, but usually a double strip of adhesive running from the base of the toes along the sole of the foot and up the calf, holding the foot in about 100 to 120 degrees equinus, will give relief (Fig. 367).

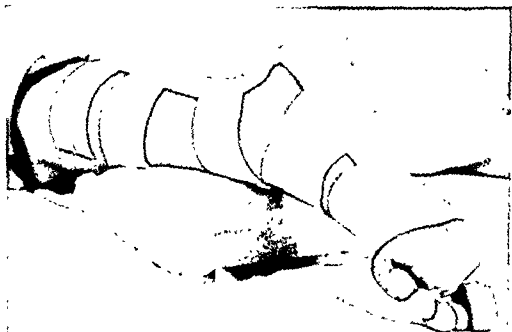


FIGURE 367. Posterior foot and leg strapping. This is useful in the treatment of acute achillobursitis or a rupture of the plantaris muscle.

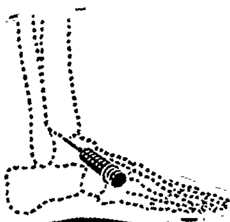


FIGURE 368. Aspiration of the ankle joint.

This strapping is easily applied. In addition, elevation of the heel may be obtained by placing a felt pad in the shoe. Occasionally complete excision of the bursa becomes necessary.

Synovitis

Synovitis of the ankle joint from injury is not a frequent occurrence, for this joint does not have the distensibility that the knee possesses. Aspiration may be done at a point on the anterolateral aspect about 2.5 cm. distal to the tip of the fibula and 1 cm. medial to it or as in Figure 368. A Gibney strapping or a pressure bandage should be applied following aspiration.

FRACTURES

Injuries to the bones and joints of the ankle are classified by Scudder (1938) according to Ashhurst's (1922) classification, and relate to the mechanism of the injury (Fig. 369).

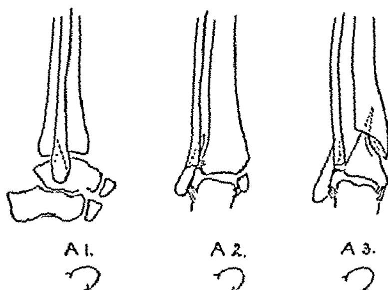


FIGURE 369. *A*, Diagrammatic drawing* illustrating the mechanism of ankle fractures. The events following forcible external rotation of the foot. (Scudder, C. L., *The Treatment of Fractures*, W. B. Saunders Co., 1938.)

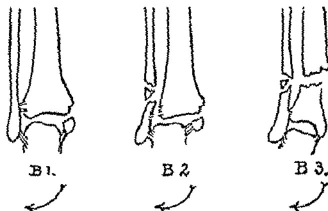


FIGURE 369 *Continued B*. Diagrammatic drawing illustrating the mechanism of ankle fractures. The events following abduction or fibular flexion of the foot. (Scudder, C. L., *The Treatment of Fractures*, W. B. Saunders Co., 1938.)

A. Fractures produced by forcible external rotation of the foot (Fig. 369A).
B. Fractures produced by forcible abduction of the foot (Fig. 369B).
C. Fractures produced by forcible adduction of the foot (Fig. 369C).
D. Vertical compression fractures (Fig. 369D).

The mechanism of production in A, B, and C is based on the leg being stationary and the foot forcibly rotated. The reverse mechanism occurs when the foot is stationery on the ground and the torsional force of the body produces the fractures.

With a combination *abduction-rotation mechanism*, (A) and (B),

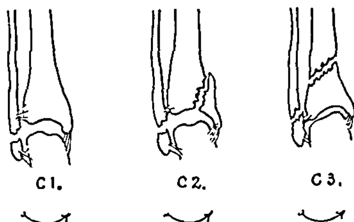


FIGURE 369 *Continued. C*, Diagrammatic drawing illustrating the events following adduction or tibial flexion of the foot. (Scudder, C. L., *The Treatment of Fractures*, W. B. Saunders Co., 1938.)

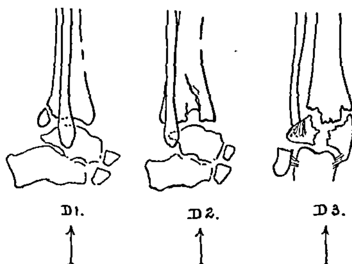


FIGURE 369 *Continued. D*, Diagrammatic drawing illustrating the mechanism of ankle fractures. The events following force transmitted upward by falls on the foot. (Scudder, C. L., *The Treatment of Fractures*, W. B. Saunders Co., 1938.)

* These drawings (Fig. 369) were made under the direct supervision of Ashhurst.

the following types of fractures, depending on the severity of force exerted, may occur which are types of Pott-Dupuytren fracture:

(1) Fractures of the external malleolus without displacement, occurring at almost a constant level just above the tibiofibular joint, combined with or without rupture of the internal lateral ligament.
(2) Avulsion of the internal malleolus with fractures of the external and outward dislocation of the astragalus.
(3) Fracture of the external malleolus with rupture or avulsion of the internal ligament or malleolus with posterior marginal fracture of the tibia and outward, backward dislocation of the astragalus.

Abduction-Rotation Fractures (A and B.)

(1) Fractures of the External Malleolus Without Displacement. These fractures are difficult to distinguish from sprains or tears of the external lateral ligament, and may be due to either direct or indirect violence. A sudden inversion of the foot may tear the lateral ligament only or produce a fracture of the fibula. The lateral malleolus may also be fractured by outward rotation of the foot which produces pressure against the lateral malleolus, and then the line of fracture is usually spiral or oblique. If the rotating or twisting force is the primary cause of the fracture, the line will be spiral, whereas if the abducting force causes a sliding laterally of the foot under the leg, an oblique fracture of the fibula at a somewhat higher level will be produced.

With the above history, whenever an ankle is swollen and tender about the external malleolus, with local point tenderness near the tip or adjacent shaft of the fibula, a fracture should be strongly suspected. Roentgen examination should be done in all injuries of the ankle if a fracture is even remotely suspected.

If there is no displacement, adhesive strapping of the Gibney type allows weight bearing and protects the ankle from any twisting and lateral motion. Full weight bearing can usually be permitted safely 3 weeks after the injury if there has been no displacement.

(2) Fracture of the Malleoli with Displacement. The abduction fracture (the usual type of Pott's or Dupuytren's fracture of first and second degree) is a displacement of the foot laterally and posteriorly with an accompanying avulsion of the internal malleolus and a fracture of the lower fibula. It is caused by a violent twist of the foot combined with rotation. A fracture of the lower third of the fibular shaft and the medial malleolus near its base, often accompanied by separation of the inferior tibiofibular articulation, occurs with the posteriorlateral displacement of the foot (Fig. 370).



FIGURE 370. Second degree Pott's fracture of the ankle (bimalleolar). Anteroposterior view (*a*); lateral view (*b*).

In the treatment of these fractures, the leg is flexed on the thigh in order to relax the calf group of muscles when early reduction of the fracture and dislocation is attempted under local or general anesthesia. The foot must not be rotated on the leg. By extremely firm lateral pressure against the malleoli, every effort must be made to compress the widened mortise, to restore the weight-bearing line to normal by accurately reducing the astragalus and to slide the foot forward. A circular plaster is applied from the toes to the midthigh with the knee flexed. The foot is held at right angles to the leg and in very slight inversion. After about 4 weeks the plaster above the knee may be removed and knee motion begun; about 2 weeks later all plaster is removed and physical therapy, consisting of baking and massage, is begun. Healing, however, is usually not solid enough to allow weight bearing before 12 weeks, as there is danger that the mortise may become widened, resulting in an unstable joint. When weight bearing is started, a Thomas heel should be attached to the shoe; this prevents the tendency toward development of a valgus attitude. Though the period of disability may be prolonged, anatomic alignment and functional restoration can usually be satisfactorily obtained if the fracture is reduced within the first 12 hours.

Open operation, with replacement of the fragments, and compression of the widened mortise between the fibula and the tibia by means of a cross bolt and fixation of the internal malleolus fragment, is often the treatment of choice.

(3) Trimalleolar Fracture. This is another type of fracture of both malleoli, complicated by backward and outward dislocation of the astragalus and fracture of the posterior lip of the tibia, carrying with it one-third or less of the articular surface. This is regarded as the third degree of Pott's fracture (Fig. 371).



FIGURE 371. Third degree Pott's fracture. Fractures of lower end of fibula, internal malleolus and posterior lip of tibia (trimalleolar), with lateral displacement of the foot.

In this type of fracture it is very difficult to maintain accurate reduction *unless an open operation is performed.* After reduction the internal malleolus and the posterior lip of the tibia are held in position by screws. Absolute reduction of the fracture when it enters into the ankle joint is essential to avoid the development of a traumatic arthritis later.

Adduction Fracture (C)

When the foot is forcibly adducted or inverted, a fracture of the internal malleolus results (see Fig. 369C). The astragalus is driven inward and upward against the internal malleolus, often fracturing it at its base and producing the so-called *first degree* fracture. If this force continues, we have a *second degree* adduction fracture in which frac-

tures of a portion of the tibia occurs along with that of the internal malleolus, as well as a rupture of the external lateral ligament and inward displacement of the astragalus. If this force is further continued, we get, in addition to the fracture-dislocation, a posterior marginal fracture of the tibia with inward and backward dislocation of the astragalus, a *third degree* fracture or a trimalleolar fracture.

Treatment. These adduction fractures are treated as above described for the abduction-rotation type, except that the reverse method of reduction is employed.

Compression Fracture (D)

The compression injuries at the ankle consist of a fracture-dislocation of the bones making up the ankle joint and are produced by a fall from a height which drives the foot forward and upward. This type of fracture can be produced when the force is from below, such as an explosion beneath the deck of a ship. The tibia and the malleoli are comminuted, the head of the astragalus may be dislocated forward or may be crushed from the fall, and frequently there is a fracture of the os calcis.

Treatment. The swelling is severe. If the os calcis is not injured the dislocation must be corrected first. After manually molding the ankle and malleoli, skeletal traction through the os calcis on a Braun frame is usually the method of choice. After 6 weeks a plaster can be applied, but immobilization should be continued for at least 3 months after the accident; full weight bearing in plaster should not start before 3 months.

These are difficult fractures to hold in position, especially when complicated by comminuted fracture of the os calcis. The late traumatic arthritis is so severe following partial reduction that panarthrodesis at the ankle may later be necessary.

DISLOCATIONS

Dislocations at the ankle joint (Fig. 372) uncomplicated by fractures are very rare. They are usually accompanied by fractures of the tibia and/or fibula.

Posterior Dislocations of the Astragalus

Backward or posterior dislocations of the astragalus on the leg are occasionally seen. They are usually produced by the dislocating force acting upon the foot while it is in an extremely plantar-flexed position.

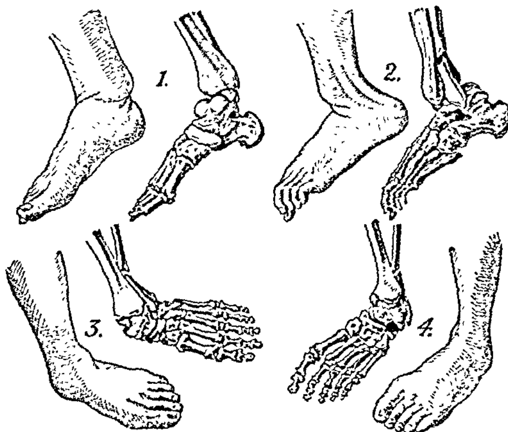


FIGURE 372. Various forms of dislocations about the ankle. (*1*) Forward dislocation of the foot; (*2*) backward dislocation of the foot, associated with fracture of the fibula; (*3*) lateral dislocation of the foot, associated with fracture of the tibia and fibula; (*4*) medial dislocation of the foot, associated with fracture of the tibia and fibula. (Hoffa.)

A continuation of this force will rupture the lateral and anterior ligaments of the ankle. It is commonly produced by a fall backwards while the foot is stationary.

Treatment. If seen early, these dislocations, when uncomplicated by fracture, are not difficult to reduce under anesthesia if one remembers to reverse the process that was required to produce the individual dislocation. The foot should be immobilized in a posterior plaster boot for 3 to 4 weeks, followed by physical therapy and very gradual weight bearing. The slow development of avascular necrosis may follow too early weight bearing.

Anterior Dislocation of the Astragalus Without Fracture

Anterior dislocation of the astragalus without fracture at the ankle is extremely rare and is the result of forcible dorsiflexion of the foot or a fall on the heel while the foot is sharply dorsiflexed on the leg. Fracture of the tibia usually occurs.

Treatment. These dislocations are treated by reversing the process of production in the same manner as described for backward or posterior dislocations of the astragalus on the leg.

Inward or Outward Dislocations

Dislocations inward or outward may occur with any severe sprain of the ankle. Careful examination will then reveal an abnormal mobility with inversion or eversion, although tearing of lateral ligaments more frequently occurs. Routine roentgenographic examination may show nothing unusual, but following Novocain injection and forcible inversion or eversion the mobility between the tibia and astragalus can be easily demonstrated.

Treatment. Immobilization in a skin-tight plaster boot with the foot in a neutral position is sufficient in the great majority of cases. This should be changed if it becomes loose after the swelling has subsided. Watson-Jones (1955) advises 10 weeks' immobilization, though weight bearing can be started after the plaster application.

Dislocation Upward Between the Malleoli

Dislocation upward between the malleoli occurs but this is usually complicated by a fracture of the tibia. When seen early and uncomplicated by fracture, simple immobilization after reduction, using a plaster boot, suffices. Gradual weight bearing is necessary as too early functional use will produce avascular necrosis of the astragalus.

EPIPHYSEAL GROWTH DISTURBANCES FOLLOWING INJURY

The epiphyseal center for the proximal epiphysis of the tibia appears in the latter half of the first year, and unites at the eighteenth or twentieth year, whereas the lower tibial epiphysis appears when the individual is about 2 years of age and unites when he is 17 to 18. The upper epiphyseal center for the fibula appears at about the third or fourth year and unites at the eighteenth to twenty-fifth, but the lower epiphysis appears at 2 and unites at 17 to 18. Therefore, before the individual epiphyses fuse, all of these locations are potential areas for growth disturbances (Fig. 373).

In young individuals, injury to the lower epiphyses of the tibia or fibula may occur with or without bony displacement. Undoubtedly many cases of so-called "ankle sprains" result in injury to the epiphyses

and produce a disturbance of the epiphyseal growth which may be noted many months after the original injury. Therefore, epiphyseal growth disturbance in children should be kept in mind in all cases of severe ankle injury, even in the absence of any evidence of fracture or obvious epiphyseal injury.



FIGURE 373. Epiphyseal separation with fracture at ankle. Epiphyseal growth disturbances would be expected in such a case.

In those cases which disclose a fractured epiphysis, or in which the fracture runs through the epiphyseal plate, early closure with cessation of growth at this point and continued growth in the uninjured portion of the epiphyseal plate may be anticipated. Many deformities at the ankle which have progressively developed months after accurate reduction show roentgenographic evidence of epiphyseal growth disturbances (Fig. 374). Parents should always be warned about the development of this complication when the ankle injury occurs in childhood. With adults, after fusion of the epiphyses has occurred, this complication does not have to be feared.

Treatment. With injury to the lower tibial epiphysis there may follow a cessation of tibial growth while the lower fibular epiphysis con-

tinues to grow (see Fig. 374). If the child has several years more to grow and the disproportion is slight, an arrest of the fibular epiphysis may be sufficient. However, if the deformity in childhood already is marked fusion of the fibular epiphysis plus an osteotomy of the tibia



FIGURE 374. Deformity of ankle resulting from old injury to the lower tibial epiphysis. Note the cessation of tibial growth and continued fibular growth, resulting in ankle joint deformity.

are required. In adults presenting this type of ankle deformity there frequently develop traumatic arthritic changes, necessitating ankle fusion.

TUMORS

Tumors of the ankle joint are rare. See Chapter 16 on Bone Tumors.

CONGENITAL DEFORMITIES

Congenital deformities at the ankle proper are unusual. Occasionally one will see the result of an intrauterine amputation through the ankle joint. These amputations have been thought to be due to constrictions

developing *in utero* but are probably primary congenital changes caused by mesenchymal defects. Occasionally a deep circular constriction about the ankle without actual amputation may be seen. Congenital absence of either tibia or fibula (see Fig. 359) with resulting ankle deformity may at times be found.

References

Ashhurst, A. *Arch. Surg.*, 4:51, 1922.

Scudder, C. L. *The Treatment of Fractures* (11th ed.). Philadelphia: W. B. Saunders Co., 1938.

Watson-Jones, R. *Fractures and Joint Injuries.* Baltimore: Williams & Wilkins Co., 1955.

14

The Foot

APPLIED ANATOMY

The bones which enter into the articulations of the foot are the seven tarsal bones, five metatarsal bones and fourteen phalanges. These are bound together by interosseous, plantar and dorsal ligaments. The foot forms normally a well-balanced mechanical arch structure along its inner border, bearing the body weight both as a passive support and as an active lever to raise and propel the body in activity. The articulations are bound together securely by ligaments, and the joints strengthened both by these and by the short intrinsic groups of muscles, whereas the long tendons of the extrinsic muscles surround the joints and give security and balance to the foot. The fascia covering the dorsum of the foot is thin and membranous and continuous above with the anterior ligaments of the ankle. On the sides it is attached to the plantar fascia. The strong annular ligament on either side of the foot is a continuation of the fascia of the leg above and the plantar fascia below. The internal and external annular ligament on either side are attached respectively to the inner and outer surfaces of the os calcis below and the internal and external malleolus above, forming canals on the inner side for passage of the flexor longus digitorum, flexor longus hallucis and posterior tibial tendons and on the outer for the peroneus longus and peroneus brevis tendons.

The bony landmarks of the foot and ankle include the internal and external malleoli, the tubercle of the os calcis and the tuberosity of the scaphoid and fifth metatarsal. In the young, slender individual it is very easy to identify the position of the tendons of the foot about the ankle. It should be remembered that the tip of the external malleolus normally lies slightly below the level of the tip of the internal malleolus and on a plane posterior to it.

On the *dorsum of the foot,* the extensor brevis digitorum muscle arises from the upper and outer aspect of the os calcis and passes downward, dividing into four tendons, the innermost of which is inserted into the base of the first phalanx of the great toe and the other three into the backs of the next three toes (Fig. 375); these, with the long extensor tendons, aid in extension of the toes.

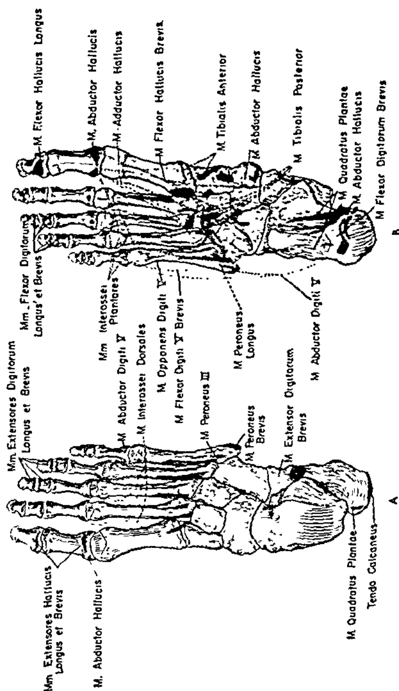


FIGURE 375. Bones of foot showing muscle attachments. (*A*) Dorsal view; (*B*) plantar view. Red: muscle origin. Blue: muscle insertion.

The *plantar surface of the foot* is covered with very thick skin and under this is found a layer of fatty tissue. Below this is the strong plantar fascia, which consists of a thick central portion and thinner lateral portions. The short flexor muscles to the toes lie beneath this fascia and are divided into three groups.

The action of the intrinsic small muscles is to aid the muscles of the leg in both abducting and adducting the foot, as well as in flexing and extending the toes.

It has been estimated that total power of the plantar flexor muscle groups is five times as strong as the dorsiflexors. These two main groups are the leverage muscles, the others serving to balance the foot and hold it in proper relation to the leg. The foot, therefore, is a lever by means of which the weight of the body is lifted and propelled. The ligamentous support of the longitudinal arch is composed principally of the inferior calcaneoscaphoid ligament, the long and short plantar ligaments and the plantar fascia. These ligaments largely support the weight of the body when a person is standing at rest.

If the foot is not balanced properly during activity, its mechanical perfection is impaired; one of the most common of improper attitudes is that of turning the feet outward while walking, so that the strain falls to the inner and weaker side of the foot.

Blood Supply. The blood supply to the foot is furnished on the dorsum by the *dorsalis pedis artery*, which is a continuation of the anterior tibial artery. This artery begins beneath the anterior annular ligament, passes downward and terminates in the first interosseous space where it divides into two branches — one to the dorsum of the big toe and the other a communicating branch which anastomoses with the terminal branch of the lateral plantar artery. The plantar surface of the foot is supplied by the medial and lateral plantar arteries, which are terminal branches of the posterior tibial artery. The *posterior tibial artery* can be palpated in the hollow between the medial malleolus and the calcaneus. The medial branch passes forward along the inner side of the toes to terminate at the inner side of the big toe. The lateral plantar artery, the larger and more important of the two branches, passes forward from its origin on the medial side of the ankle, then outward to the base of the fifth metatarsal bone, where it turns inward, crossing the sole, and terminates by anastomosing with a communicating branch of the dorsalis pedis artery. That portion of the artery which crosses the sole from the outer to the inner side is called the plantar arch.

Nerve Supply. The nerves supplying the sole of the foot are the medial and lateral plantar. The former is the larger of the two terminal branches of the posterior tibial nerve, and arises in the hollow of the os calcis, accompanying the medial plantar artery. The lateral plantar nerve is the other terminal branch and accompanies the lateral plantar artery. The medial plantar nerve corresponds in a general way to the sensory distribution of the median nerve in the hand; the lateral plantar nerve corresponds to the ulnar nerve. Therefore, the medial plantar nerve supplies three toes and a half of the fourth toe, the lateral plantar supplies the little toe and the other half of the fourth toe. The dorsum of the foot is supplied by the superficial peroneal nerve, which is one of the terminal branches of the common peroneal nerve, and by the deep peroneal nerve, which terminates as the medial and lateral terminal branches. On the inner side of the ankle, just between the internal malleolus and the os calcis, lie a number of important structures of practical importance. From the medial to the lateral side they are in the following order: tendon of the posterior tibial muscle, tendon of the flexor longus digitorum muscle, posterior tibial artery and vein, tibial nerve and tendon of the flexor longus hallucis muscle.

EXAMINATION

As in the examination of all the joints the patient must be adequately draped and in a good light, and, if possible, made to walk so that the patient as a whole as well as any particular deformity may be observed. *Inspection* will show whether he limps or is obviously in pain when weight bearing. It will show the position, appearance, size, color and attitude of the foot under activity. The patient is then seated opposite the observer, preferably on a slightly higher level, so that the foot can easily be taken in the hands and carefully examined and *palpated.* After the position of the bony landmarks is noted, one should passively manipulate the foot to determine its range of motion, and then have the the patient actively move it in all possible directions.

The foot should be examined for any circulatory disturbances. The examiner should routinely palpate for the pulsation of the dorsalis pedis and posterior tibial arteries. It must be decided whether the range of motion is normal; if not, is the abnormality due to contractures of the soft tissues or is the limitation of motion bony in character? Are the callosities on the balls of the feet or on the tops of the toes, or any place where underlying deformities or improperly fitting shoes may

produce a callus? Always search between the toes for soft corns. Try to decide by inspection and palpation whether there are any obvious congenital defects, such as an unusually short first metatarsal bone or an unusually long second metatarsal bone, webbed toes, overlapping toes, hammer toes, or bunions. The examiner must decide whether the patient is balancing properly when he walks, and whether the foot deformity can be passively and easily corrected but recurs on weight bearing, as we find in the flaccid type of weak foot. Do the tender points on the dorsum or sole correspond to those characteristic of chronic foot strain or is there a localized evidence of some systemic affection? Is there underlying evidence of injury or disease to the bones or soft tissues of the foot? These and other questions will occur when the feet are being examined carefully and routinely, but it must be remembered that the art of observation and examination will be gradually developed as the examiner becomes more adept and more skillful in recognizing pathologic conditions. Failure to make the correct diagnosis is often due to a casual and hasty examination.

Laboratory Aids. Roentgenograms are invaluable and should be taken whenever necessary. Many times, if in doubt, a roentgenogram of the opposite foot acts as a control and may make the diagnosis of early disease or an incomplete fracture much more obvious. Oscillometric readings are of diagnostic value in circulatory disturbances of the feet, and the use of a simple blood pressure cuff may be of similar assistance in peripheral vascular disease. Blood sugar determinations may sometimes explain the reason for a chronic foot ulcer. A blood Wassermann or Kline test and a routine blood count and urinalysis often aid in the diagnosis.

The Arches

The demands made upon our feet — which serve as both active and passive agents — are tremendous and necessitate an extremely strong and flexible mechanism. The balancing movements of the foot when walking and running are dependent upon both the bony architecture and the soft tissue covering of muscles and ligaments.

All the weight passes directly to the astragalus (talus) and thence is distributed to the twenty-five other bones of the foot which are arranged in a series of arches. The astragalus rests upon the os calcis, which is the largest bone of the foot, and, as previously stated, is the only bone in the foot that has no muscle attachments, being kept in place by the pressure of the bones abutting it and by the slant of their

articular surfaces. The seven tarsal bones are irregularly shaped blocks and, with the metatarsals, form the essential weight-bearing part of the foot. The complete longitudinal arch (Fig. 376) of the foot may be made by an imprint in plaster taken of the opposed feet. This cast



FIGURE 376. *Left*, plaster impression of left foot. From this, a plaster mold is made and a stainless steel Whitman plate is fashioned for the longitudinal arch, as shown. This is useful as a corrective plate for pronated feet in childhood and adolescence. *Center*, a combination arch supporting both longitudinal and transverse arches. *Right*, a longitudinal arch support made of fiberboard, leather and chamois from a tracing of the right foot. This is useful for adult patients with flaccid, weak feet.

will represent a rather flat dome with the highest or thickest part at the astragalonavicular joint. From this point the arches descend sharply to the tuberosities of the os calces and to the outer border of the feet. By sectioning this plaster longitudinally, one can demonstrate the longitudinal arch, and on cross section the contour of the transverse arch can be seen.

The *longitudinal arch* can itself be separated into two parts, the inner and outer division The outer division is formed by the os calcis, the cuboid and the two outer metatarsal bones, the highest point being at the calcaneocuboid articulation. This arch is supported by the heel

behind and the heads of the fourth and fifth metatarsals in front. It is rather flat in its contour and is completely obliterated when the patient is standing or walking. Therefore, the outer border of the normally balanced foot should receive the major portion of the body weight when the patient is standing. Due to its stability and low-slung structure, it is not usually the site of symptoms relating to foot strain.

The inner division of the arch is composed of many joints which have greater mobility and greater opportunity for strain than the joints of the outer division. This inner division rests on the heel behind and in the forefoot mainly on the head of the first metatarsal. It is made up of the os calcis, astragalus, scaphoid, three cuneiform and three inner metatarsal bones. The astragalus is the keystone, resting on the superior surface of the os calcis, and is a part of the inner division of the longitudinal arch. The bony configuration of the foot makes the inner border particularly susceptible to foot strain. Therefore, slight intoeing in walking is the position of strength, whereas the position of weakness is out-toeing.

The width of the foot at the level of the metatarsal heads reveals that the heads do not lie transversely across the front of the foot. Actually, the second metatarsal head projects further forward than the others, a metatarsal arch being formed with a dorsal convexity in order to give strength and elasticity to the forefoot. This region is called the *transverse arch*. At times the metatarsal heads may become unusually prominent and the soft pad of fatty tissues obliterated so that callosities form in these areas, especially under the heads of the second, third and fourth metatarsal bones.

The foot is a finely balanced mechanism which not only is made up of different shaped bones bound together by ligaments and supplied by nerves and blood vessels but also is supported when used actively and passively by both the intrinsic short muscles of the foot and the tendons of the long extrinsic muscles which arise in the leg and insert into the foot. The foot has a multiplicity of movements to accommodate it to whatever type of surface is walked upon.

Many foot troubles are the result of improperly fitting shoes and socks, as well as hard unresisting floors and streets that permit the foot to be used as a stiff boardlike structure and not as an articulated extremity. Nature intended it to be a finely articulating mechanism, which must have vigorous exercise of its component parts on rough surfaces to prevent atrophy of disuse. The muscles primarily support the foot when it is in action but when it is used as a passive support,

such as in standing, the ligaments and the bony articulations bear the greater part of the strain. Therefore, attention to the proper balance and attitude of the foot during walking is essential. In walking the entire weight of the body is alternately borne by each individual foot; the feet, therefore, should be held parallel and the weight of the body borne slightly more on the outer border of the foot.

In the properly balanced foot, a plumb line dropped from the middle of the patella down over the leg should strike between the first and second toes (Fig. 377). *The out-toeing attitude, so frequently as-*

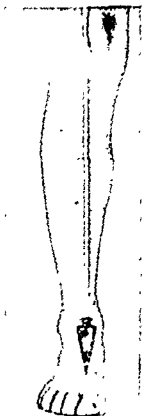


FIGURE 377. Normal foot balance A plumbline dropped from the midline of the patella strikes the cleft between the first and second toes.

sumed, is a poor one and it is the first and earliest evidence of mechanical imbalance. If persisted in, definite symptoms of foot strain appear later.

Easy graceful carriage in walking denotes good health, perfect synchronization and muscular co-ordination. We can walk with a gait that is jarring and awkward, in an attitude that predisposes to muscle strain and chronic deformity, or the normal foot can be used as an articulated lever to raise and propel the body smoothly and gracefully; which

method is used depends largely upon our understanding and appreciation of body balance and body mechanics.

Accessory Bones

Ordinarily each of the tarsal bones arises from a single center, but occasionally an additional center may develop separately from the

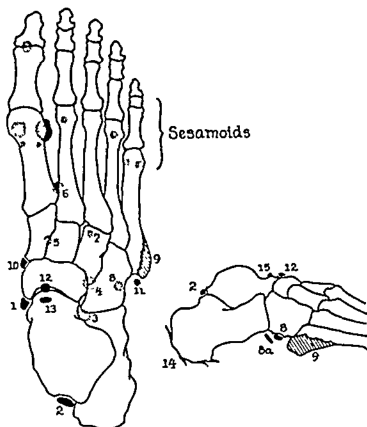


FIGURE 378. Accessory bones and sesamoids of the foot.

1. Os tibiale externum (accessory scaphoid)
2. Os trigonum
3. Secondary os calcis
4. Secondary cuboid
5. Intercuneiform
6. Intermetatarsum
7. Uncinatum
8. Peroneal sesamoid (articulating with inferior surface of cuboid)

8a. Peroneal sesamoid
9. Epiphysis of fifth metatarsal
10. Paracuneiform
11. Vesalianum
12. Astragalo-scaphoid ossicle
13. Os subtibiale (Fairbank)
14. Calcaneal spurs
15. Astragaloid spur

rest of the bones and become an accessory bone (Fig. 378). The following are the more frequent locations:

(1) The principal center of ossification of the astragalus appears at the seventh month of gestation. In the astragalus an additional

center is occasionally deposited in the posterior portion of the bone, which may remain separate from the bone and forms the *os trigonum.*

(2) The os calcis, with its primary nucleus, appears at the sixth month of gestation. Cases have been reported of two separate centers developing and forming two heel bones.

(3) The cuboid arises from a single nucleus which appears at about the time of birth, but an accessory bone (*os peroneum*) may develop in the lateral angle between the fifth metatarsal and the cuboid, lying in the peroneal tendons.

(4) The primary nucleus of the navicular (scaphoid) appears in the fourth year, but the tuberosity of the navicular occasionally develops separately and remains distinct from the rest of the bone, being called an *accessory scaphoid.* It is always small and usually bilateral.

The practical importance of all accessory bones of the foot is that they are sometimes mistaken for fractures. Their typical position, size and smooth, rounded outline should differentiate them from fractures. It is occasionally necessary to excise an accessory bone if the tissues over it become swollen and tender.

POSTURAL DEFORMITIES

Acquired Pes Planus (Weak Feet)

Noting the attitude of the feet in walking many times permits one to prophecy future foot trouble for the individual. Aching feet, with localized pain, or general foot fatigue is so common a complaint that imbalance often is overlooked in the early stages of foot strain. The term "weak feet" has been applied to those cases which develop foot strain through an improper attitude of walking and is preferable to the term "flatfeet." Many times foot disability bears no relation to whether the arch is flat or not, but is evidence of mechanical imbalance. Certain races of people, particularly the Negro, present a structurally flatter arch than the Caucasian; therefore the appearance of the arch is not a true criterion for foot trouble. Again certain types of feet are mechanically unstable, such as the high arched, cavus foot in the slender type of individual. Congenital pes planus is discussed on page 627.

The *persistence of abduction* or out-toeing is one of the earliest signs of impending foot disability and develops as follows: As the foot comes in contact with the ground the leg is twisted inward and the weight falls upon the inner side of the foot. The astragalus rotates

downward and inward on the os calcis, thus stretching the calcaneo-navicular, deltoid and interosseous ligaments. The scaphoid and the head of the astragalus undergo continuous pressure. An actual compression and lowering of the longitudinal arch may follow, accompanied by a bulging of the inner side of the foot, the so-called pronated attitude. Therefore, the lowering of the arch is of secondary importance in the deformity, and this must be kept in mind in deciding upon the principles underlying treatment. The term "weak feet" is used to describe all types of attitudinal foot disability, and the pain in these cases is caused not because the arch is flat, but because this attitude produces symptoms of strain, usually extending over a long period of time and caused by improper walking.

Many of these feet begin to give pain and disability in late adolescence or early adult life, often because the continuous strain of a regular occupation is being undertaken for the first time. All the tissues of the body become less resilient with increasing age and accommodative changes in the soft structures occur; the bones themselves may even show evidence of abnormal pressure and adaptation to the imbalance. The muscles on the inner border of the foot become overstretched while the abductors or peroneals and in some instances the calf muscles become contracted and shortened by the habitual posture of abduction.

Early symptoms are a sensation of weakness, discomfort and fatigue or strain about the inner part of the foot and ankle, with a dull ache in the calf of the leg, often running up into the back. *Sometimes low back pain will secondarily arise from foot trouble.* The patient may only state that he turns his ankle frequently, or he may notice sensitiveness and swelling and, in general, a stiffness of the foot, so that he dreads to cross rough surfaces. Very often he states that he has difficulty buying comfortable shoes or that after new shoes are worn a short time they become uncomfortable.

Types of Weak Feet. The position in which the patient holds the foot during standing or walking demonstrates a varying degree of abduction and valgus (Fig. 379). In the more severe types of weak feet, walking may be done almost on the inner border of the ankle with the toes pointed markedly outward. Obviously this improper attitude continued over a period of years will give rise to a fixed deformity of the foot involving all its component parts. Therefore, a relaxed, *flaccid type* of weak foot may undergo accommodative changes. Other varieties are the *spastic type*, in which the foot is drawn into the attitude

of abduction by the spastic peroneal muscles, and the *rigid type* or completely stiff foot.

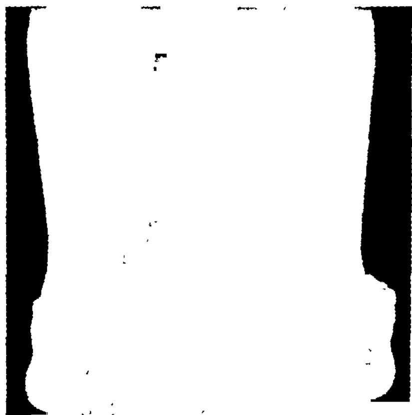


FIGURE 379. Abducted and pronated feet indicative of foot strain.

The Flaccid Weak Foot

This makes up the greatest percentage of so-called *flatfeet* and is particularly frequent in the young individual. Many children roll their ankles inward when they begin walking, presenting not only foot relaxation but a general muscular lack of tone, so that they have been called "double-jointed." All of their joints have an excess range of motion. This is often noted in the rapidly growing child. When an infant begins to walk, the foot often presents an apparent flatness of the longitudinal arch; many times this is more apparent than real as the chubby foot gives this appearance due to its fatty tissue. As the foot develops the child may automatically learn to walk correctly, balancing slightly on the outer border of the foot with the toes pointing straight ahead. The result is a well-developed arch. On the other hand, the rather overweight infant or youngster many times develops an attitude of weak feet under the stress and strain of unbalanced movement and weight bearing.

Sometimes insistence upon too early weight bearing in infants is a factor.

Examination of the foot reveals that the foot can be passively moved normally in every direction and that there is a normal degree of plantar flexion, dorsiflexion, inversion, eversion and rotation of the forefoot.

One of the important movements to determine is the degree of dorsiflexion possible. This is done (1) by the examiner pushing up against the sole of the foot while the knee is held fully extended, and (2) by having the patient actively dorsiflex the foot as much as possible. Normally, with the knee extended and with the foot held in a slight degree of inversion, the foot can be dorsiflexed passively and actively 10 to 15 degrees less than a right angle. However, a short heel cord will prevent this.

It is in the constant act of walking that vicious foot deformities develop from a *contracted Achilles tendon* and these are produced as follows: In walking the body is normally leaning forward at the termination of each step, forcing the foot on the ground into dorsal flexion. The constant repetition of this foot position in patients with an abnormally short heel cord stretches the soft tissues in the mediotarsal region. The foot, therefore, assumes the abducted and pronated attitude. The plantar ligaments are stretched and a flatfoot attitude develops even though the posterior part of the foot may be in slight equinus due to the contracted heel cord. This type of weak foot is frequently seen in women who have worn high heel shoes for many years.

Clinical Picture. The flaccid type of weak feet is found primarily in the younger age brackets. The clinical picture may show only one foot affected, but usually both feet are equally involved in the pronation. There may be a persistence of foot fatigue with all the other obvious signs and symptoms of mechanical foot strain. The points of tenderness in a flaccid weak foot are not uniform, although certain localities are more subject to stress and strain than others. Pain usually occurs over the inner aspect of the foot in the region of the inferior calcaneoscaphoid ligament, for here there is a gradual stretching of the soft tissues.

As the foot assumes an abducted position in relation to the leg, the external malleolus may even come in contact with the outer surface of the os calcis, and at this point the patient frequently complains of local tenderness.

With a history of generalized foot fatigue, pain in any portion of

the foot on weight bearing is presumptive evidence that we are dealing with *mechanical foot strain.* Symptoms vary from mild discomfort and difficulty in finding comfortable shoes to almost complete disability. The feet often become painful and swollen and in the severe cases, the tenderness in the longitudinal arch with local heat may even resemble an infectious process.

Treatment. Primarily treatment is intended to correct the foot balance during activity. No underlying disease causes this foot disability, but rather a long-standing improper attitude in weight bearing. If the patient is old enough to desire correction of his walking position and is co-operative and intelligent, the problem of cure is a much simpler one.

As the earliest sign of weak feet is a persistent abduction of the feet, the first form of treatment must begin by correcting this. If the patient is a gangling, loose jointed, relaxed type of individual, general body exercises are most urgently required, as well as attention to the feet, for the mechanism as a whole needs improvement in muscle tone and co-ordination. If, however, the process is limited to the feet, there are several methods of approach.

Foot exercises. Foot exercises are most important to overcome the tendency to use the foot in the improper attitude. This means that often the inverters of the foot, the anterior and posterior tibial muscles, have become relaxed and that the bones along the inner border of the foot have become slightly displaced inward and downward, with accompanying stretching of their ligamentous attachments.

If a child is old enough and intelligent enough, he can be taught the proper position of the feet in walking by diagrams or by doing his foot exercises while standing in front of a mirror. However, one of the most important steps is the matter of proper instruction in order that a balanced foot may be developed. When the child begins to walk a very practical preventive in the development of weak feet is to raise the inner border of the sole and heel with a wedge of leather inserted along the inner border of the shoe approximately ⅛ inch to ¼ inch thick as shown in Figure 380. This simple maneuver against valgus and out-toeing aids in educating the child to balance correctly at an early age.

In adults and children excellent foot balance may be obtained with exercises. The basic principle here is to strengthen the inverters of the foot and constantly to bear the weight slightly on the outer border of the foot, walking with the feet parallel. This results in a normal relation-

ship in the articulations of the foot by relaxing the chronic tension on the strained ligaments, and by developing an elastic, springy gait. To be most useful the exercises should be repeated slowly in front of a long mirror several times each day.



FIGURE 380. Elevation of the inner border of the heel and sole of shoes by inserted leather wedges (1/8 inch for children and 1/4 inch for adolescents). This often relieves fatigue in the foot and leg.

These foot exercises are as follows:

(1) Stand with feet parallel, knees stiff. Turn over so that you are standing on the outside edge of the feet, the soles of your feet facing each other as nearly as possible. In doing so keep knees stiff. Repeat ten times.

(2) Toes in, heels out. Rise on toes and come down without touching the floor with heels. Repeat ten times.

(3) Toes in, heels out. Rise on toes. Come down so as to form a circle with the outside edge of the feet from toe to heel. Repeat ten times.

(4) Cross feet, left foot on right side, right foot on left side, so that toes and heels are on parallel lines. With legs rigid, rock sidewise from left to right. Repeat ten times.

(5) Knees stiff, feet parallel. Walk on the toes without bending the knees for one minute.

(6) Feet parallel. Walk on the outside of the feet without bending the knees for one minute.

(7) Feet parallel. Bring toes and heels together as far as possible, making an effort to grip with them. Repeat ten times.

(8) Walk up and down, toeing in as far as possible, for one minute or more.

It is most important that the patient become "foot conscious" if he wishes to obtain the greatest benefit from foot exercises. In order to train the foot to balance correctly as well as to relieve chronic muscle

the foot on weight bearing is presumptive evidence that we are dealing with *mechanical foot strain.* Symptoms vary from mild discomfort and difficulty in finding comfortable shoes to almost complete disability. The feet often become painful and swollen and in the severe cases, the tenderness in the longitudinal arch with local heat may even resemble an infectious process.

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advisable, for it gives an insecure base as the patient walks and renders foot strain and ankle sprain likely. Several good types of women's shoes are made today and a Cuban heel is, as a rule, perfectly satisfactory.

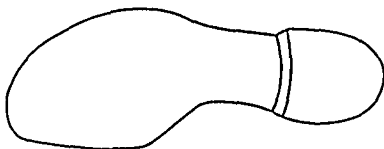


FIGURE 382. Essential features of a good shoe: broad heel, narrow shank, and straight inner border.

Certain women patients who have worn high heels over a number of years present a definite shortening of the tissues of the posterior calf group of muscles. These muscles must be gradually stretched but never by suddenly wearing a flat heel as this will in turn produce further strain and disability in an already unstable foot. Occasionally a zigzag tenotomy of the tendo achillis to correct the equinus becomes necessary if stretching methods fail.

There may be some specific reason why a stiff shank shoe is desirable, but as a rule in the mild type of weak foot a flexible shank permits the intrinsic muscles of the foot to be restored to their normal tone and permits a certain amount of useful interarticular play between the bones of the foot.

The Thomas heel. Use of the Thomas heel (Fig. 383) is in certain cases of tremendous benefit. It should be applied under the direction of the orthopaedic surgeon, for many of the commercial shoes advertised as fitted with Thomas heels are in reality only a simple extension forward of the heel. The original Thomas heel not only extended medially forward on the shank of the shoe to approximately opposite the astragaloscaphoid joint, but was also increasingly wedged from the posterior to the anterior border and from the lateral to the medial border so that the highest point of this wedge was at the inner tip of the projected heel. Therefore, under weight bearing a distinct upward and medial thrust under the apex of the long arch causes the patient to walk in the proper attitude.

Wedges. Wedges in the shoe are a favorite way of shifting the weight toward the outer border of the foot. A wedge of leather is applied between the layers of the sole and heel from ⅛ to ¼ inch thick,

strain, an adhesive strapping holding the foot in slight varus is applied (Fig. 381).



FIGURE 381. Strapping of the foot as treatment for slight varus. A doubled strip of 2-inch adhesive plaster is applied at the level of the external malleolus and extended under the foot up to the upper third of the leg on the medial surface. Shorter lengths of adhesive are then applied about the foot and leg as shown. They should never completely encircle the foot or leg.

Shoes. Another approach to the problem of foot balance is the wearing of the correct type of shoe. There is no uniform agreement regarding the best type of shoe to be worn but it may be pointed out that the *shoe should fit the foot rather than trying to make the foot fit any particular type of shoe.* In general, a narrow waist to the shoe, a moderately broad heel and a straight border along the inner sole (Fig. 382) are recommended, so that when the inner borders of the shoes are opposed their surfaces are touching for almost their entire length. As a rule this type of shoe is easily obtained for men and children, but with women's shoes the selection is somewhat more difficult. Pointed shoes, too tight shoes, too short shoes, too narrow shoes are physiologically incorrect. Though flat, broad heels cannot be recommended for every patient, the high French heel with its small base is not

take place within the foot articulations and corrects abduction — two most essential factors in correcting the flaccid type of weak foot. The foot is permitted motion so that the individual in walking is almost forced to walk in the correct attitude. The flange on the outer border

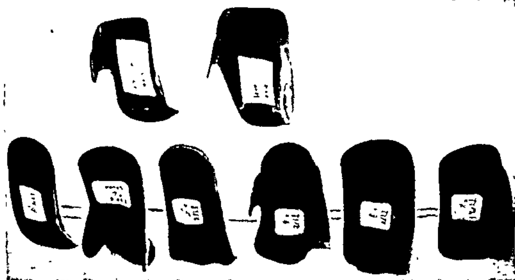


FIGURE 384. Types of foot braces and two types of Whitman arch supports. The latter are particularly satisfactory for the flaccid weak foot.

of the foot plate is the original feature of the Whitman foot plate, for by pressure on the lateral border of the foot, it prevents the foot from going into abduction when walking. The patient is, therefore, forced by the pressure of the outer flange against the foot to turn the foot into an attitude of slight adduction. Also the inner contour of this foot brace presses upward against the longitudinal arch of the foot. This type of foot brace does not raise the arch in the ordinary sense, for many times in foot strain the arch is essentially not lowered, but relieves the soft tissue strain that abduction produces and thereby gives relief from the symptoms of foot ache and fatigue. Any arch or mechanical foot support must fit the contour of the individual foot very closely. The only correct way to construct these foot braces is by taking an exact mold of the foot, modifying it as the individual needs of the foot require, and modeling the arch support upon this cast.

The best way to make the Whitman foot plate is as follows: The patient is seated on a stool and in front of him is placed a low slanting stool. A good grade of dental plaster is prepared by mixing it in water to a batter consistency. This is poured over a piece of muslin cloth approximately 15 inches square which has previously been placed over a thin pillow on the slanting stool top. The foot is powdered with

tapering off as the wedge advances laterally toward the outer border of the shoe (see Fig. 380). The shank is not wedged. The cowboy type of boot heel slopes downward and forward so that the weight is

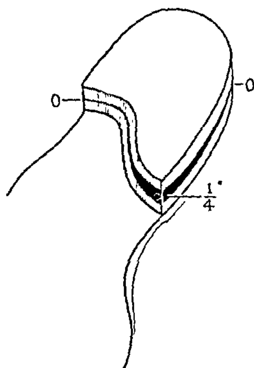


FIGURE 383. Thomas heel. The thickness of the wedge should be greatest on the anterior medial border of the heel, which has been advanced forward level with the astragaloscaphoid joint. It then tapers off posteriorly and laterally.

borne directly under the tuberosity of the os calcis and this type of heel is at times very comfortable to those patients with mild foot strain.

Insoles and foot plates. All types of material have been inserted within the shoe to relieve foot strain, from the simple commercial type of flexible leather insole, which is rather ineffective, to the corrective Whitman foot plate (Fig. 384) made of stainless steel or some other light noncorrosive material.

To make correctly a well-fitting, effective foot brace is a very difficult procedure and for this reason the market is flooded with all sorts of well-advertised but rather ineffective foot supports.

In dealing with a child one needs not only some temporary relief from foot strain, but also a corrective type of brace. For the weak foot in a growing child the Whitman type of brace, if fitted properly, is mechanically effective. It permits a controlled amount of motion to

superior surface of the nonarticular surface of the os calcis to the inferior surface of the neck of the astragalus, or a bony bar restricting movement between the os calcis and navicular, excision is indicated.



FIGURE 385. Calcaneonavicular bar.

(3) Many of these patients should have the foot thoroughly stretched in all directions so that interarticular adhesions may be broken up and full mobility of the foot restored following the removal of the mechanical obstruction.

Following this a well-fitting plaster boot extending from the toes to the knee, with the foot in very slight varus and at right angles to the leg, is applied. The patient is soon allowed to walk in this well-molded support. After 6 weeks the boot may be bivalved and baking and massage begun daily. However, in favorable cases the plaster may be removed at the end of a few weeks and baking and massage with daily reapplications of adhesive strapping applied to retain the corrected position and to restore normal movement. Later a proper type of foot brace may be made, but it must be remembered that the spastic type of weak foot must always be converted into a flaccid type in order to expect any form of foot plate to give relief.

The Rigid Weak Foot

The rigid type of weak foot is rarely found in the young age group, being much more commonly noted in patients over 40, and as the name indicates, the foot is held rigid. Roentgenograms usually show distinct arthritic changes throughout the foot, narrowing of the joint spaces and definite lipping of the joint margins. The foot is usually in a valgus attitude, and any attempt at inversion is practically completely restricted. With the exception of motion at the ankle joint, the other foot movements are largely absent. It is essentially a chronic

talcum or greased with petrolatum, and as the plaster begins to set the outer border of the foot is placed in it. The plaster is then molded by the operator about the ankle and foot while holding the foot at right angles to the leg and with light pressure on the dorsum of the first metatarsophalangeal joint. The foot is held perfectly steady until the plaster has set. The foot and plaster then are dusted with powder and a second batch of plaster paste poured over the foot, completely covering it, and molded neatly. After this has hardened the upper shell is carefully removed, the foot lifted out and the two halves strapped together and filled with a plaster paste of the casting type of plaster. This is harder and more resistant than the dental plaster. The shells are then carefully removed and an exact cast of the foot remains. This must be trimmed out so that the arch of the foot is raised to the necessary degree and then the metal support made on this cast. This permits a well-fitting support to be made which is in reality a corrective type of foot brace. In the adult, where relief of pain and not foot correction is the primary aim, it is often unnecessary to have the outer flange applied to the brace.

In many cases of foot strain not only the longitudinal area but also the transverse arch of the foot is subject to fatigue and pain; then the metatarsal area of the foot must also be supported (see Metatarsalgia, p. 600).

The Spastic Weak Foot

The second type of weak foot is the so-called *spastic* weak foot which is recognized in the majority of cases before or during young adulthood. In this instance the foot assumes an abducted attitude because of spasm of the peroneal muscles, and any attempt at inversion of the foot passively is both painful and restricted. Actively the patient is unable to invert the foot. A sprain of the ligaments in the foot or ankle or an articulating bony spicule or bar between the os calcis and navicular bones (Fig 385) may be the underlying cause of spasm developing Harris and Beath).

Treatment. (1) If the case presents only muscle spasm the restriction of motion may be overcome gradually by daily stretching the foot into inversion and applying adhesive plaster with the foot in the corrected position, i.e., slight varus. This method of treatment may be quite painful and prolonged. The underlying etiologic basis should be corrected, if it can be found.

(2) When there is an incomplete bony bridge extending from the

the metatarsal heads (Fig. 387) or a metatarsal elevation of cork or rubber placed within the shoe will give relief. Efforts should always be made to increase the local circulation by contrast baths, massage and



FIGURE 386. Felt pad strapped just behind the heads (shown by black spots) of the metatarsal bones (for metatarsalgia).



FIGURE 387. Transverse leather bar placed obliquely across the shoe just behind the metatarsal heads (for metatarsalgia).

corrective foot exercises. Adequate treatment of the associated problems is necessary, such as excision of the neuroma when present.

arthritis of the foot, and the symptoms are caused by the eburnated arthritic joints rubbing against each other on movement, as well as by ligament and muscle strain.

Treatment. No attempt need be made to restore this foot to its normal flexibility. Stretching with manipulation must be done very cautiously in order to avoid making the condition worse. Ordinarily a carefully fitting leather arch support and shoes with a small inner wedge over the heel and sole will give some relief. Baking and massage increase the local circulation of the foot and are therefore of benefit; rarely is any surgery advisable in this type of weak foot.

Metatarsalgia (Morton's Disease)

Metatarsalgia is a painful affection opposite one of the metatarsophalangeal joints, usually the fourth, and may begin as a burning sensation in the ball of the foot or a sudden cramp, the pain radiating into the foot and leg. A cramplike sensation in the anterior metatarsal region of the foot is aggravated by walking, as the heads of the metatarsal bones become pressed together. It also may present a painful callus. It is more common in females than males and is rarely seen in early life, most of the cases occurring after 30 years of age.

Etiology. Metatarsalgia was originally thought to be due to the compression or pinching of the plantar nerve, but is probably in the great majority of cases secondary to relaxation and strain of the metatarsal arch.

The center of the forefoot is not only depressed but may develop large tender callosities under the heads of the second, third or fourth metatarsal bones. Narrow or ill-fitting shoes aggravate the pain. It is a very common affection and may be found whenever the normal mechanics of the foot are affected. Frequently a plantar wart is associated with this condition.

Occasionally, however, a *neuroma* will involve one of the plantar nerves, giving the characteristic pain of metatarsalgia, and then excision of the mass is indicated.

Treatment. If there is no underlying bone disease producing fixed deformity and the pain is due to mechanical foot strain, a felt pad placed just behind the heads of the metatarsals (Fig. 386) will afford considerable relief. This should be combined with foot exercises directed toward strengthening the tone of the intrinsic muscles, and this in turn will improve the anatomic position of the metatarsal arch A transverse leather bar placed across the sole of the shoe just behind

inserted into the lateral side near the base of the proximal phalanx of the big toe, becomes shortened and contracted and aids in aggravating the deformity. Often a hypertrophic or traumatic arthritis is present and pressure is produced upon the digital nerves, causing severe pain.

Hallux valgus deformity is often accompanied by deformity of the toes which may be distorted by tight or pointed shoes or tight hose. The foot-wear theory, however, cannot account for the varus of the first metatarsal, but shoes may play some part in the development of the hallux valgus for it is uncommon in races that walk barefooted. It may be that wearing shoes interferes with the natural use of the intrinsic muscles. While outward deviation of the great toe with a bursa over the first metatarsophalangeal joint (see Fig. 388) is the most obvious deformity, the width of the metatarsal area is also increased, giving rise to the so-called splayfoot.

Symptoms may be of two types: those due to pressure on the bunion and those due to the secondary deformities and the metatarsalgia that is so frequently present. The bunion may be inflamed and very tender, being aggravated by pressure of the shoe. The bursa may even be distended with fluid and sometimes becomes infected. The amount of pain depends on all these factors as well as the foot strain that may be produced throughout the foot in the cases of pronation. Callosities formed over the plantar and medial surface of the foot are evidences of the faulty attitude of the foot in walking. In severe cases, disability is often great; these patients may hobble along on markedly pronated and abducted feet with callosities scattered throughout the dorsum of the toes and at any point which is subjected to constant pressure of the shoe. The contracted extrinsic tendons on the extensor surface of the foot throw the heads of the metatarsals out of their normal alignment, allowing tender callosities to develop in the soles of the foot and giving rise to the clawfoot type of deformity, often with dislocation at the metatarsophalangeal joints.

Treatment. In the milder cases, treatment consists of correcting the foot wear and fitting the patient with longitudinal or metatarsal arch supports. In more severe cases in which the metatarsophalangeal joints are subluxed and roentgenograms show evidence of cartilage destruction as evidenced by a distinct narrowing of the joint spaces and displacement of not only the big toe but all of the lesser toes, an operation is the method of choice. In the severe cases, the operation must of necessity be a multiple one, not only correcting the bunion, but also improving the function and the cosmetic appearance of the

Hallux Valgus

Hallux valgus is commonly called a *bunion* and consists of an outward deviation of the big toe in its relation to the first metatarsal bone. It is accompanied by a bony enlargement on the medial side of the head of the first metatarsal. Usually when this condition has existed for a length of time, the rubbing of the shoe produces a bursa at this point, and the bony overgrowth with its bursa constitutes the term *bunion* (Fig. 388).



FIGURE 388. Severe grade of bunions and flat feet.

Etiology. Hallux valgus is sometimes caused and usually made worse by too pointed, narrow shoes. If the patient presents a pronated foot, this may be a contributing factor. It does occur in childhood on a congenital basis but will ordinarily be noted in later life, and in the severe forms all the metatarsal bones can be seen adducted and all of the toes abducted, giving rise to a very severe and disabling deformity.

If the deformity persists, various secondary characteristics make their appearance, i e., the extensor hallucis longus tendon, which normally runs over the first metatarsophalangeal joint, is deviated to the outer side as a bowstring, the adductor transversus muscle, which is

Treatment. Only the milder cases may be corrected by any type of retentive apparatus worn in the shoe. The treatment of choice is resection of the flexed interphalangeal joint, and correction of the deformity by producing a surgical fusion between the deformed phalanges with the toe in the fully extended position. Temporary use of a Kirschner wire inserted through the distal, middle and proximal phalanges is helpful in preserving immobilization while fusion is progressing; fusion usually occurs 6 to 8 weeks after the operation.

Hallux Rigidus

Hallux rigidus is a painful affection at the first metatarsophalangeal joint, characterized by restriction of motion, particularly dorsiflexion. The great toe is usually held in slight plantar flexion, and attempts to



FIGURE 390. Hallus rigidus of the first metatarsophalangeal joint. Note the proliferative bone changes and the narrowing of the joint space.

extend it are painful and always restricted. There may be a burning, throbbing pain in the foot but in the mild cases there seems to be only a spasm of the flexor longus hallucis. This deformity is found sometimes associated with a weak arch and may be aggravated by too tight

foot. Stretching of the toes or subcutaneous tenotomy and capsulotomy of the metatarsophalangeal joints of the foot, plus proper arch supports and shoes, should be considered essential as well as surgically correcting the hallux valgus deformity.

For the hallux valgus, the Silver operation (Silver, 1923) or the McBride operation (McBride, 1935) are suitable for the moderate cases; in the severe type, the Keller operation (Keller, 1921) is one of the most satisfactory. The old Mayo operation, with excision of the head of the first metatarsal bone, has largely been discarded.

Hammer Toe

Hammer toe, or contraction of one of the interphalangeal joints of the toes, usually the second (Fig. 389), is painful and always deforming. When the interphalangeal joint is severely flexed, a tender callus often forms on the tip of the toe and over the dorsum of the flexed portion, caused by rubbing against the shoe. Occasionally these calluses may become infected.

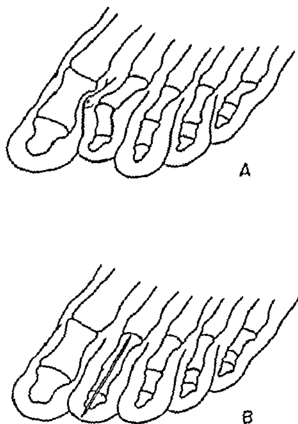


FIGURE 389. Hammer toe deformity. (*A*) Flexion contracture at the proximal interphalangeal joint of second toe with callus formed over the joint. (*B*) Kirschner wire temporarily placed through phalanges after a surgical excision of the proximal interphalangeal joint

temporary character; therefore adhesive strapping, foot supports, more gradual resumption of activity and physical therapy are all useful in relieving the temporary discomfort.

(3) Acute bursitis may develop in those persons whose occupation requires long hours of walking on hard surfaces. Policemen and mailmen are particularly prone to an acute bursitis, probably adventitious in type. Rest is necessary when very acute, but local Novocain and/or Hydrocortone injection, radiation to the heel, and in rare instances surgical exploration may be necessary to shorten the convalescence. A protective hollow-heel type of foot support should be worn for some months after the acute symptoms disappear.

(4) The appearance on the roentgenogram of a spur on the inferior surface of the os calcis at the point of attachment of the plantar fascia does not always prove that this is producing the disability. The spur may or may not be the cause of symptoms. The term "gonorrheal-spur" is a misnomer as there is no definite evidence that gonorrhea is the etiologic agent. Many os calces with roentgen evidence of spurs are symptom-free. Also, the direction of the spur growth is an indication of its pain-producing property. Those spurs almost parallel to the under surface of the bone rarely cause a painful heel, while those obliquely directed often cause painful symptoms.

Frequently heel-cupped arch supports, raising the shoe heel or wearing sponge rubber or felt pad in the heel of the shoe will relieve the symptoms, but occasionally surgical removal of the spur and bursa are necessary. Some cases are very refractory.

(5) Bone tumors are rarely found in patients with heel pain, but these must be considered and roentgenograms will disclose them.

(6) See Apophysitis under Epiphyseal Abnormalities (p. 625).

DISEASES

Tuberculosis

Tuberculosis of the bones of the foot is occasionally seen. The astragalus is the most frequently involved bone in the foot; the os calcis is next in frequency, and the cuboid and external cuneiform are involved in the order named. Tuberculosis follows injury in the majority of cases but often no known cause can be assigned, and the condition is erroneously diagnosed as rheumatism or chronic sprain until well-marked bone destruction is produced.

Pathology. See Chapter 2.

shoes. At times it is caused by an instinctive effort to support the weak arch by gripping the ground with the big toe, thereby causing the toes to be held in a habitually flexed attitude. In the more severe cases roentgenograms (Fig. 390) show evidence of arthritic changes in the shape of the articular surface of the head of the first metatarsal, with sometimes a coronal ring of bone on the dorsal surface.

Treatment. Simply supporting the longitudinal arch with a properly fitting foot plate may be adequate, but as a rule it is necessary to limit or completely prevent motion at the first metatarsophalangeal joint. This can be done by placing a long thin flexible piece of metal in the sole of the shoe along the inner border, as shown in Figure 391, to

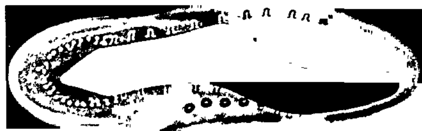


FIGURE 391. Metal strip inserted between the layers of the sole of the shoe in order to restrict motion at the first metatarsophalangeal joint.

restrict or prevent motion in the affected joint. Rarely is surgery necessary, but sometimes a Keller type of operation, i.e., excising the proximal fourth of the proximal phalanx of the big toe, is necessary.

Painful Heels

This is a comparatively common complaint that may arise from a variety of conditions, the usual complaint being "pain on the inferior surface of the heel on weight bearing." Roentgenograms should be taken routinely.

Some of the more usual causes are:

(1) Pain and tenderness after long standing or activity on a hard surface due to strain of the plantar fascia and intrinsic muscles. This may sometimes give rise to a mild traumatic periostitis as shown by the roentgenogram or to a local bursitis. The condition may be relieved by hollow heel arch supports or radiation; in the stubborn case a change of occupation may be necessary.

(2) After any long period of recumbency, the heels may be sensitive and painful on beginning ambulation. This condition is of a

drug, such as penicillin, are indicated. In the acute stages roentgenograms show soft tissue swelling within the first week after onset, but no bone evidence of acute osteomyelitis until later. If the condition is chronic the roentgenogram may indicate sequestrum formation. More radical surgery is then needed.

Osteomyelitis of the Os Calcis. Osteomyelitis of the os calcis (Fig. 392) rarely occurs. It is characterized by discoloration and swelling about the heel or the entire foot. The bone may be secondarily involved



FIGURE 392. Osteomyelitis of the os calcis.

as a metastatic lesion from some other osteomyelitic focus. In the acute stage, incision and adequate drainage is satisfactory but in chronic osteomyelitis of this bone wide surgical exposure is necessary. Commonly a central lesion involves to a greater or lesser degree the cancellous bone, this condition later being complicated by multiple sinus formation. Involucrum formation may occur but it is a most unusual event in this bone, which is in striking contrast to osteomyelitis of the long bones.

In treating this condition, the split-heel approach of Gaenslen (Gaenslen, 1931) is most satisfactory. This is made with the patient

Clinical Picture. The tissues become somewhat swollen as well as presenting an increase in local heat. Muscle spasm with restriction of motion is found. Unless there is bone destruction, the tuberculous nature of the lesion is usually not correctly diagnosed. Occasionally tuberculosis involves the subastragalar joint. Lateral motion of the foot then causes severe pain, and the range of adduction and abduction are actively restricted and passively lost. The positive tuberculin test is of significance only in the young child. Roentgenograms even in the early stages show bone atrophy and later, definite bone destruction.

Treatment. In the early cases rest and support is indicated in order to guard against the tendency of valgus which the foot usually assumes. A brace is usually not as satisfactory as a plaster casing. As a rule the disease continues to progress, and abscess formation with sinuses complicates the picture. If the astragalus alone is involved, early astragalectomy is recommended. If the subastragaloid joint only is involved, early arthrodesis of this joint accompanied by antibiotic therapy offers the best chance for cure.

In the adult the condition is much more serious because of the economic time factor involved to effect a cure. Generally, when the adult presents tuberculosis of several of the tarsal bones with abscess formation, amputation at the site of election in the leg — about 7 inches below the knee — is the method of choice. Disease of the tarsal bones shows a distinct tendency to extend from one bone to another until the entire foot is involved. A *chest roentgenogram* should always be made, for the prognosis is poor in those cases with active pulmonary tuberculosis.

Osteomyelitis

Osteomyelitis may affect the tarsals, metatarsals or phalanges, the long bones being most commonly the seat of infection and the staphylococcus most frequently the offending organism. It can be of hematogenous origin or due to infection from the introduction of a foreign body into the foot.

Pathology. See Chapter 2.

Clinical Picture. The heat, swelling, redness, pain, limitation in motion, and throbbing are all characteristic of an acute infectious process, and may be accompanied by a pronounced constitutional reaction with a sharp rise of temperature.

Treatment. Incision and drainage combined with wet dressings to the affected part and heavy doses of the suitable chemotherapeutic

irritation, for the edge of the nail acts as a foreign body, aggravating the condition.

Treatment. In mild cases a small piece of cotton may be gently insinuated underneath the lateral border of the nail, or wet soaks to the toe often relieve the pain, and cure follows. In those cases which do not respond to simple conservative treatment, surgical excision (Fig. 393) of a portion of the nail and heaped-up granulation tissue with thorough curettage of the nail bed is indicated. With a severely infected nail bed, only complete removal of the nail and curettage of the nail bed will cure the condition.

Onychogryposis (Club Nail)

Onychogryposis is hypertrophy of one or more of the nails of the fingers or toes, although the nail of the big toe is by far the most frequently affected. The thickened and deformed nail becomes twisted, elongated and shaped somewhat like a horn from which it gets the name "onychogryposis." It is usually found in the elderly person and is often found associated with faulty foot hygiene. There develops a disturbance of nail bed growth, the dorsal layers growing more rapidly than the plantar. This results in a curling of the thickened nail (Fig. 394).



FIGURE 394. Club nails. (From Dickson and Diveley, *Functional Disorders of the Foot*, J. B. Lippincott Co.)

lying face down with a support under the ankle. The incision is made beginning on the plantar surface of the foot from the level of the tuberosity of the fifth metatarsal bone, extending over the heel and splitting the Achilles tendon in its lower 3 or 4 cm. This allows the diseased os calcis to be split in two halves and turned outward as the leaves of a book. It gives adequate exposure and allows the granulation tissue and loose bone to be completely removed. The wound is left open after packing with petrolatum gauze. A plaster boot is applied, the wound healing by secondary intention. This method has the great advantage of giving adequate exposure and is far preferable to excision of the entire os calcis. It does leave a rather deep scar on the weight-bearing surface of the heel, which may later be obliterated by a plastic operation.

Ingrown Toenail (Onychia)

Ingrown toenail most frequently involves the big toe, although an infection about the base and periphery of any of the nails may occur. The pressure of too tight shoes aggravates the condition. In the big toe the granulation tissue about the infected nail border is the result of

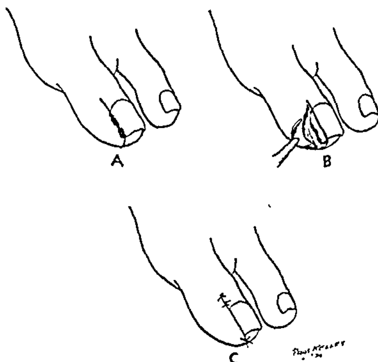


FIGURE 393. Operation for excision of ingrown toenail. (*A*) Line of incision for the skin flap, (*B*) skin flap retracted and line of incision for excision of nail portion and subcutaneous tissue; (*C*) incision closed. (From Dickson and Diveley, *Functional Disorders of the Foot*, J. B Lippincott Co.)

ing a second generation of warts through inoculation, and the warts occur frequently at an area of lowered resistance, such as a callus, and may be due to lymphatic infiltration and blockage.

Clinical Picture. Many present a cauliflower-like appearance when the cornified layer of skin is shaved off and usually are exquisitely tender on direct pressure. They bleed easily through the tips of the papillae. They should not be confused with the ordinary callus which is often found in the metatarsal portion of the foot and is due wholly to faulty foot mechanics. The gross cauliflower-like appearance, the punctate tips which easily bleed on trimming and its infectious nature are features characteristic of verruca plantaris, but not of the ordinary callus.

Treatment. Faulty foot balance is often present and should be corrected by improved foot hygiene, arch supports and proper shoes (Lake, 1943). The plantar wart frequently responds to cauterization with an electric needle, repeated each week if improvement is noted. Radiation and radium are often of assistance and various acids have been used as cauterizing agents. Surgery should be used on these warts as a last resort. If the wart is only locally excised, a painful tender scar frequently remains. Complete excision of the wart with the adjacent toe and metatarsal bone has been recommended (Dickson, F. D., and Diveley, R. I., 1944; Dickson, J. A., 1948) and may occasionally be advisable for the very intractable cases. However, when surgery becomes necessary, removal of the metatarsal head alone is a simpler procedure and is usually satisfactory in the resistant cases. Excision of the big toe should be avoided if possible.

Dermatophytosis (Interdigital Ringworm; Athlete's Foot)

Etiology. Dermatophytosis is caused by the *Trichophyton* fungus and is very frequently transmitted through the medium of bath mats and wet floors in gymnasiums. It usually first affects the interdigital cleft between the fourth and fifth toes.

Clinical Picture. Beginning as a moist or scaly dermatitis with pruritus, resembling often a patch of wet blotting paper, cracks in the skin develop which become secondarily infected. The epidermophytosis may spread extensively between the toes and over the dorsum of the foot. Circulatory impairment seems to be a factor favoring development of the condition.

Diagnosis. Diagnosis can be confirmed by laboratory methods. After scraping the lesions, mounting the scraped material in 10 to 30 per cent

Treatment. The deformed nail may be so troublesome from shoe pressure or catching on the stocking that its complete removal and curettage of the nail matrix become necessary. Rarely will the condition respond to foot cleanliness or conservative measures such as local applications. Following nail removal a proper fitting of shoes becomes necessary to avoid subsequent local irritation. If there is a recurrence of deformed nail, amputation of the distal phalanx of the toe may be necessary.

Plantar Warts (Verruca Plantaris)

Etiology. There is a close affinity between varruca plantaris and the ordinary cutaneous wart. They have been regarded as warts that have been pushed into the dermis and subjected to the pressure of weight bearing, thereby developing a thick cornified layer on the sole of the foot. Most frequently they are found on the plantar surface of the foot and heel (Fig. 395), varying in size and number. All are not be-

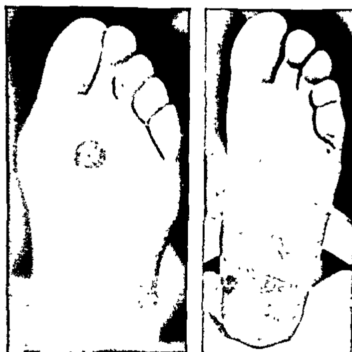


FIGURE 395. Plantar warts in the foot. These are two of the more frequent sites (Hauser, E. D W, *Diseases of the Foot.*)

lieved to be due to the same etiologic agent, but there appears to be a familial tendency to certain of them.

The following points must be kept in mind: A filtrable virus has been obtained from the verruca plantaris which is capable of produc-

situation and every effort must be made to secure early adequate drainage and freedom from weight bearing.

Treatment. Wet dressings, nonweight bearing and an immediate prophylactic dose of tetanus antitoxin, 1500 to 2000 units intramuscularly, constitute the emergency treatment, followed by intensive chemotherapy. The foot must be carefully watched for swelling or ascending infection. If the wound is produced by broken glass or penetrating wood, every effort must be made to remove any particles of foreign material and devitalized tissue.

FRACTURES

Fractures of the Talus (Astragalus)

Fracture of this bone alone is uncommon. It is more frequent accompanying a fracture of the os calcis or as a part of the picture in fracture-dislocation at the ankle joint region. It occurs most commonly in young adults following severe trauma, such as a fall from a height or a severe blow on the outer side of the foot.

Clinical Picture. A swollen, tender and painful joint with limitation in joint motion usually constitutes the clinical picture. Occasionally a small chip fracture of the posterior process may occur accompanied by very few symptoms; usually, however, the fracture is through the body or neck of the bone, giving rise to severe disability.

Early and adequate roentgenograms are essential and must include oblique views as well as the routine anteroposterior and lateral views.

Treatment. In fractures of the posterior process simple immobilization in a plaster of Paris boot with the foot in slight equinus for a few weeks is all that is needed. The prognosis is good.

In severe cases with fracture through the neck of the talus, closed reduction should be attempted and if unsatisfactory, open reduction is advisable. Immobilization in a plaster boot is needed for 6 to 8 weeks, without weight bearing. A snug-fitting walking iron can be incorporated in the plaster a few weeks after reduction.

In fractures of the body of the talus there may be crushing of the superior and inferior articular surfaces of the bone; in the adult a panarthrodesis is advisable. If the injury is not so severe, skeletal traction through the os calcis, with the limb supported on a Braun frame (see Fig. 354), may permit restoration of joint function.

Complications. Often this type of fracture is accompanied by a fracture or dislocation of the subastragalar or ankle joints, and these must be appropriately treated.

potassium hydroxide and allowing it to stand 2 to 24 hours, the organisms can be readily seen under the microscope. Recurrences are exceedingly common.

Treatment. In its early stages attention must be paid to foot hygiene with frequent changing to clean socks or stockings. Thoroughly drying the foot and use of zinc stearate powder may abort its spread. Many remedies have been suggested for the more severe case, all of which may fail to effect a cure. Walking barefoot on the beach may help.

A 2 per cent solution of picric acid in 50 per cent of alcohol to which a few drops of glycerin have been added, applied night and morning, is sometimes very effective. Soaking the affected area in a full strength iodine solution or 1/4000 potassium permanganate every night is at times helpful. In some of the mild cases a 10 per cent solution of salicylic acid in collodion effects a cure. Radiation has been recommended and in certain cases appears to be very specific.

SOFT TISSUE INJURIES

Sprains

The most frequent injury to the region of the foot is sprain about the outer surface of the ankle joint, which is discussed under ankle injuries (p. 564).

Occasionally, the longitudinal arch region undergoes an acute sprain. Routine strapping with an inner sole felt lift, with the foot strapped in slight varus (see Fig. 381), is usually adequate to take care of this satisfactorily.

Lacerations of soft tissues require the usual thorough washing and cleansing, and, depending upon their extensiveness and the time since injury, the wound may be either closed tightly or left partly open. Chemotherapy following surgery is indicated.

Penetrating Wounds

Penetrating wounds are probably the most common wounds to the soft tissue of the feet and should never be treated casually because of their potential danger. Penetration of a nail through the shoe into the sole of the foot is a dangerous accident because of the possibility of tetanus developing. If the wound has been received in contaminated soil, or if the nail is known to be rusty, it is safer to make an incision and cauterize the tract of the penetrating agent. A red, swollen, throbbing, tender foot following this type of accident represents a dangerous

take roentgenograms of both calcanei — a lateral and a plantar-dorsal view. This latter consists of holding the foot in maximum dorsiflexion by means of a bandage about the forefoot. The axis of the roentgen tube is directed at a 40 degree angle on the plantar surface, with the cassette under the heel and lower leg (Fig. 397).

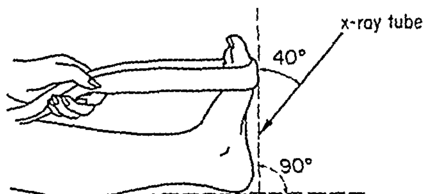


FIGURE 397. Technic of taking roentgenogram in suspected os calcis fracture. Cassette is placed on table under heel.



FIGURE 398. Normal tuber joint angle (40°). This angle is diminished when the body of the os calcis is fractured.

The *tuber joint angle* is measured by projecting a line along the superior nonarticular surface of the normal os calcis and another line along the inferior surface of the talus (Fig. 398). In the normal foot an angle of approximately 40 degrees is formed at the intersection of

Severe injury to the astragalus is frequently followed by a late avascular necrosis of the bone. Occasionally an astragalectomy without backward displacement of the foot is necessary, but more frequently an arthrodesis of the astragalus to the bones contiguous to it is preferred for the recent injury.

With severe trauma to the astragalus resulting in fracture and/or dislocation, the prognosis for restoration of normal function must be very guarded.

Fractures of the Os Calcis (Calcaneus)

The os calcis is the most frequently fractured bone of all the tarsals. In these cases the history is quite similar, and this injury must always be suspected if the patient falls from a height, landing on the heel. In World War II many of these fractures occurred on shipboard when the concussion from depth bomb charges heaved the deck upward, producing a comminuted fracture of this bone.

Clinical Picture. Severe swelling and tenderness below and posterior to the ankle, widening and shortening of the heel and loss of lateral

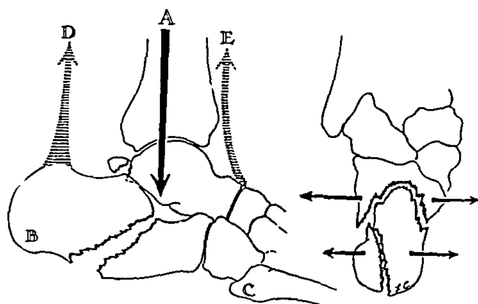


FIGURE 396 Fracture of the os calcis, showing forces involved.

motion are all characteristic features. Generally these fractures are comminuted following no fixed pattern, but depending upon the force received (Fig. 396). If the fracture enters the astragalocalcaneal joint, the danger of subsequent traumatic arthritis must be borne in mind.

Roentgen Examination. If one calcaneus is fractured it is useful to

from the toes to the knee. When the fracture is so comminuted that open operation becomes necessary every effort must be made to preserve the articular surfaces, restoring them to their normal position and filling in the defect in the body of the bone with transplants from the crest of the ilium as recommended by Palmer (1948).

(4) Page and Mumford (1945) have pointed out that the time-honored principle in all fracture work is to bring the distal fragment into line with the proximal fragment. Therefore, considering the posterior fragment as the proximal one, the reduction must be obtained by full plantar flexion of the distal fragment as follows:

The foot is placed in full equinus with the knee flexed to nullify the pull of the tendo Achillis and the lateral calcaneal displacement is corrected by a clamp or by hand pressure; a plaster casing is applied extending from the toes to the groin with the foot in equinus and knee at right-angle flexion. The long plaster cylinder above the knee is removed a few weeks later and knee exercises started, for restoration of knee function is thereby hastened. The short leg plaster is retained without weight bearing for 6 to 8 weeks, then bivalved and physical therapy and active motion started with increasing weight-bearing activity. The patient must not be returned to full weight bearing until bone healing is complete. This procedure will assure full function of ankle motion in a large majority of os calcis fractures.

In fractures of the calcaneus complicated by the fracture entering the subastragaloid joint, reduction may be attempted by the methods described above; the great majority, however, later develop a post-traumatic arthritis. Therefore, arthrodesis of this joint when it is involved is usually advisable. Roentgenograms should be taken at intervals, since up to a few weeks it is possible to remanipulate these fractures with a compression clamp and apply a new plaster. Weight bearing should not be allowed for at least 12 weeks, and every effort must be made to restore the tuber joint angle.

After the plaster is removed but before weight bearing is resumed, a course of active exercises combined with baking and massage is very helpful in developing the strength of the muscles. A guarded prognosis must be given with fracture of the os calcis.

Cuboid, Cuneiform and Navicular Fractures

Fractures of the cuboid, cuneiform and navicular bones may be treated by molding the fragments and applying a plaster boot for 6 weeks, during which period the patient is allowed a walking iron (Fig.

the lines on the posterior aspect of the ankle joint. With flattening of the longitudinal arch and upward displacement of the calcaneus, this angle is much reduced (Fig. 399) and every effort should be made to re-establish it in order to restore the normal relationship of these bones.

Treatment. Fractures of this bone must be treated upon the same principle as all other fractures; that is, an exact reduction must be attempted early. The reduced fragments are fixed in position until bony union has occurred.



FIGURE 399. Fracture of the os calcis with a decreased tuber angle.

(1) With a severely comminuted type of fracture it is difficult to obtain complete reduction. Treatment must be early, vigorous and thorough in order to mold the heel back into position and restore the normal contour of the os calcis. The powerful pull of the Achilles tendon must be relaxed by flexing the knee and placing the foot in plantar flexion during the manipulation. The impaction must be thoroughly broken up; this can be done manually or by using a felt-covered mallet, after which the instep of the foot is placed over a triangular block and the os calcis molded as nearly as possible into position.

(2) If the Achilles tendon has contracted, carrying along with it a large fragment of bone, open reduction with internal fixation of the fragment is the method of choice.

(3) Occasionally the os calcis is broken into several large pieces. It may then be reduced by skeletal traction. Pass one wire or pin transversely along the superior, non-articular surface of the os calcis, another through the lower end of tibia. Produce dis-traction and restoration of the tuber angle as checked by lateral roentgenogram while the leg and foot are suspended on a Bohler frame. A plaster boot is then applied

to 6 weeks. After placing a felt pad in the metatarsal region of the foot just posterior to the heads of the bones (see Fig. 386), a plaster boot should be applied from the toes to the knee with the foot at right angles to the leg, taking particular care to restore the natural concavity to the shaft of the metatarsal, since this is of far more practical importance than a slight degree of lateral displacement.

Intramedullary fixation, extending a Kirschner wire through the head and along the shaft of the metatarsal, and immobilizing the foot in plaster for a few weeks, permits early accurate reduction. The wires are then withdrawn, but plaster fixation and partial weight bearing are continued for 6 to 8 weeks.

March Fracture

The term "march fracture" usually refers to a fracture of the shaft of one of the metatarsal bones (Fig. 401), but other bones may be similarly affected.



FIGURE 401. March fracture.

Clinical Picture. This type of fracture occurs sometimes in ordinary walking in the normal healthy individual, but is more frequently found in the soldier who is subjected to unusual exertion and foot strain.

400). The plaster must be carefully shaped about the tibial tuberosities at the knee so that they will receive most of the weight when walking. Attention should be directed toward restoring the longitudinal and transverse arches of the foot by molding the plaster, but as a rule the permanent disability is slight.

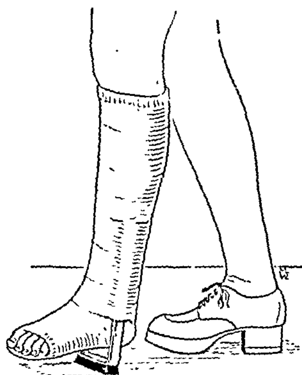


FIGURE 400. Plaster cast with caliper attached. Note that the shoe on the opposite foot is raised to simplify walking. (Hauser, E. D. W., *Disease of the Foot*, W. B. Saunders Co., 1950.)

Phalangeal Fractures

Fractures of the phalanges are often painful and it may be difficult to obtain anatomic correction because of the small size of the bones involved. Such fractures seldom result is serious disability, but are usually accompanied by considerable swelling of the soft parts. Reduction and protection in a plaster boot for several weeks are usually sufficient when combined with elevation of the foot.

Metatarsal Fractures

Fractures of the metatarsals are caused by both direct and indirect violence, though the former is more usual. They may result in a major disability of the foot, but as a rule they heal without disability if properly supported. Skeletal traction through the phalanges is rarely necessary, but the foot should be relieved from weight bearing for 4



FIGURE 402. Subastragalar dislocation Anteroposterior view (*a*); lateral view (*b*).

reduction. If recognized late a subastragalar arthrodesis becomes necessary.

Interphalangeal Joint

Dislocations at the interphalangeal joint can be easily reduced when acute and require a very short period of immobilization. They rarely cause any serious disability.

EPIPHYSEAL ABNORMALITIES

Osteochondritis of the Tarsal Scaphoid (Köhler Disease)

Osteochondritis of the tarsal scaphoid (Köhler's disease) is an uncommon affection which is seen in children. Clinically it produces local tenderness and pain with limping but very little redness or local heat. Diagnosis is made primarily on the roentgenogram appearance (Fig. 403). Osteochondritis of the tarsal scaphoid is a degenerative avascular necrosis due to interference of the blood supply of this bone, possibly the result of strain or contusion. The roentgen appearance shows that in comparison with the other bones of the foot the scaphoid stands out because of its density in outline, its decrease in size and the rough-

Often congenital shortening of the metatarsal bone of the great toe is a contributing factor. The shaft of the second metatarsal is frequently involved. The symptoms develop gradually, and continued weight on the fractured bone causes local spreading of the postfracture hematoma with excessive callus formation, so that the first symptom may be a complaint of "a lump in the foot" rather than that of pain. It has given rise to the occasional mistaken diagnosis of a primary malignant tumor.

Differential Diagnosis. (1) March fracture has been confused with a periosteal thickening of one or more of the metatarsal shafts, the so-called Panner's disease. (2) A pathologic fracture in the foot may be the result of a metastasis from a malignant tumor elsewhere. (3) A benign lesion, such as a bone cyst or chondroma, may also weaken bone structure sufficiently to allow fracture by direct injury. All of these should be considered in the differential diagnosis of a march fracture.

Treatment. A walking plaster boot should be applied for a few weeks, followed by foot strapping and exercises stressed toward improving the tone of the intrinsic muscles of the foot.

DISLOCATIONS

Tarsometatarsal Joints

A dislocation occurring at any of the tarsometatarsal joints results in a marked deformity of the foot but if treated early can be easily reduced under anesthesia. Immobilization for 3 or 4 weeks, holding the foot at right angles to the leg and molding the plaster well under the longitudinal arch, prevents redisplacement. If seen late an open operation, at which time the joint is fused, may be necessary to reduce the dislocation properly.

Subastragalar Dislocations

Subastragalar dislocations (Fig. 402) are not common, but occasionally are seen when inversion and adduction of the foot suddenly occurs. The dislocation gives rise to a great deal of swelling about the foot and obvious deformity, the foot being displaced laterally or medially, depending on the mechanism of production. The foot should be manipulated and the dislocation reduced early, after which a snug-fitting plaster boot is worn for several weeks before weight bearing is instituted. If reduced early, there is very little permanent disability, and active movement in the foot may be begun 4 to 6 weeks after the

Clinical Picture. There is pain and tenderness around the affected bone with some thickening and swelling, suggestive at a casual glance of a metatarsalgia.



FIGURE 404. Freiberg's disease. Note avascular necrosis of the head of the second metatarsal bone with flattening of articular surface.

Treatment. Supportive treatment in the very acute stage consists of wearing a plaster boot. Later a metatarsal pad usually suffices to relieves the patient of symptoms, although the square flattened shape to the head of the second metatarsal persists. Rarely is it ncessary to resect the deformed metatarsal head.

Apophysitis

Apophysitis is a disturbance of the epiphysis of the os calcis which results in slight local swelling and sometimes acute tenderness on the inferior aspect of the heel. It occurs particularly in boys between 10 and 15 years of age. It is probably due to chronic pressure or strain upon the growing epiphysis and may produce a low grade inflammatory reaction. The roentgenogram shows an irregularity or fragmentation of the epiphysis (Fig. 405).

Treatment. Weight bearing is painful and the best treatment is rest and relief of strain and pull of the Achilles tendon. In mild cases the heel of the shoe is elevated ¼ to ½ inch; in resistant cases a plaster

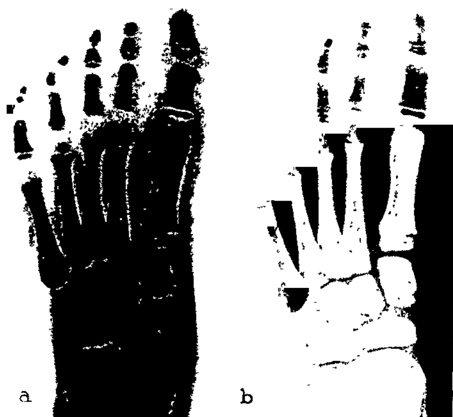


FIGURE 403. (*a*) Kohler's disease of tarsal scaphoid, (*b*) same case 20 months later with complete revascularization of the avascular necrosis.

ness of its borders. If weight bearing is permitted, the bone becomes warped, crushed or flattened.

Treatment. Conservative treatment is advised in these cases. If the foot is protected from weight bearing for a few months in plaster, it tends to a spontaneous revascularization with very little if any residual disability Recent investigations lend some support to the idea that a hypothyroidism may exist and that the local injury is only a contributing factor. Generally some type of foot support should be worn after the plaster is discarded, and it will probably take six months to a year for complete revascularization of the scaphoid bone to occur.

Osteochondritis of the Second or Third Metatarsal Bone (Freiberg's Disease)

Freiberg's disease occurs in childhood and presents a somewhat similar pathologic picture to that of osteochondritis of the tarsal scaphoid. It is a degenerative avascular necrosis involving the head of the second or third metatarsal bone (Fig 404). Trauma is possibly a contributing factor.

Clinical Picture. There is pain and tenderness around the affected bone with some thickening and swelling, suggestive at a casual glance of a metatarsalgia.



FIGURE 404. Freiberg's disease. Note avascular necrosis of the head of the second metatarsal bone with flattening of articular surface.

Treatment. Supportive treatment in the very acute stage consists of wearing a plaster boot. Later a metatarsal pad usually suffices to relieves the patient of symptoms, although the square flattened shape to the head of the second metatarsal persists. Rarely is it ncessary to resect the deformed metatarsal head.

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Treatment. Weight bearing is painful and the best treatment is rest and relief of strain and pull of the Achilles tendon. In mild cases the heel of the shoe is elevated ¼ to ½ inch; in resistant cases a plaster

boot applied from the toes to the knee with the foot in slight equinus will usually relieve the patient of the local pain and swelling. A longitudinal arch support with a cupped heel may at times be helpful in reducing pain.



FIGURE 405. Apophysitis. Note fragmentation of the epiphysis

TUMORS

Primary *malignant bone tumors* are unusual but occasionally even metastasis to the bones of the foot may occur.

The most common types of *benign lesions* found in the foot are the *enchondroma* and the *exostoses*. Occasionally chondromas and bone cysts are found (see Chapter 16).

Subungual Exostosis

Subungual exostosis is an outgrowth of a small bony tumor arising under the nail bed near the tip of the toe, usually the big toe. The exostosis arises from the dorsum of the distal phalanx, lifting up the matrix and displacing the nail as it continues to force its way between the tip of the nail and the pulp portion of the toe.

The exact cause is unknown although trauma or infection appears to initiate the majority of cases.

The growth is locally tender and pressure on the nail in walking and wearing shoes aggravates the local tenderness and predisposes to infection. Roentgenograms show the bony outgrowth clearly.

Treatment. In the early case a lateral incision will permit excision of the exostosis; a short convalescence follows. In those cases that have progressed until the matrix has become ulcerated, the entire nail and exostosis must be removed and the nail bed scraped. The wound then is allowed to heal by secondary intention. In rare instances amputation of the terminal phalanx becomes desirable at the time of primary surgery.

Subungual Glomus Tumor

This small painful tumor, characterized by a mass of blood vessels, arises underneath the nail and involves the nail bed in more than half the cases. Injury to the nail may precede the appearance of the tumor, which has a purplish tint. The tumor may give rise to excruciating pain and sensitiveness involving first the region affected and then spreading to the entire foot. It can be noted as a slight discoloration beneath the nail, being an overgrowth of the glomus bodies which occur normally in the skin. These benign lesions resemble a small hemangioma (Hauser, 1950).

Treatment. Surgical removal is advocated.

CONGENITAL DEFORMITIES

Congenital Pes Planus

The congenital flat foot is a severely pronated and abducted long narrow foot. The deformity is usually bilateral, but one foot may be more involved than the other. This type of foot may present such underlying congenital causes as a short first metatarsal bone, accessory scaphoids or other skeletal defects and may require radical treatment for its correction.

There is elongation of the neck of the astragalus, convexity of the inner border of the foot and shortening of the outer border.

Clinical Picture. Symptoms of early fatigue after walking, especially developing in the adolescent period, are usual, and cosmetically, the foot is badly in need of correction.

Treatment. This is not the type of foot that lends itself to conservative care, an operation on the skeletal architecture being the treatment of choice. A triple arthrodesis can so reconstruct the appearance of

the foot as to be perfectly satisfactory, but this does destroy mobility in the tarsal bones. White (1940) advocated removing a wedge from the astragalar neck to shorten the medial border of the foot and then placing this wedge into a vertical osteotomy through the os calcis to lengthen the outer border of the foot. This wedge lies just proximal to the calcaneocuboid joint. The foot is then held in as much varus as needed and at a right angle to the leg while a plaster boot is applied. The boot should be worn for 8 weeks. If the heel cord is shortened, this can be lengthened during the same operation. This operation succeeds in preserving a good deal of mobility in the foot.

Congenital Talipes (Clubfoot)

A very important and frequently seen orthopaedic condition is congenital clubfoot. Various deformities of congenital origin occur in the foot, but there are four simple varieties of clubfeet: (1) *talipes equinus*, or the plantar-flexed foot; (2) *talipes calcaneus*, or the dorsiflexed foot; (3) *talipes varus*, or the inverted foot; and (4) *talipes valgus*, or the everted foot.

The four basic varieties occur with all combinations, such as talipes equinovarus, talipes calcaneovalgus, and so on. The congenitally deformed foot may be the only deformity found. Since clubfeet sometimes accompany spina bifida, exstrophy of the bladder, harelip, congenital dislocation of the hip and other congenital defects, a thorough physical examination should always be made.

Etiology. The exact etiology of all congenital deformities is unknown. Malposition *in utero* with intrauterine pressure, although not the direct cause, is undoubtedly an influence in producing deformity. Undoubtedly certain families have a greater tendency to congenital deformities than others, but in many of the cases nothing bearing upon the deformity appears in the family or personal history. The cause is at times mechanical, due to the foot *in utero* remaining for a long time in a strained or fixed position which produces a deformed attitude at birth. Congenital talipes is far more common in males than in females and slightly more unilateral than bilateral, the right foot being more frequently affected.

Congenital Talipes Calcaneovalgus

Congenital talipes calcaneovalgus (calcaneus) is a mild type of clubfoot frequently seen in the newborn infant, and often requires no

treatment. Due to the foot being held in the calcaneus position *in utero* the calf group of muscles become stretched and active plantar flexion is temporarily lost. Stretching gradually the contracted tissues on the dorsal surface of the ankle and applying a light plaster casing with the foot held in plantar flexion for a few weeks usually suffices to overcome the calcaneus. The power in the calf group of muscles returns. This type of congenital anomaly is rarely a problem. The acquired calcaneus is usually caused by infantile paralysis (see Chapter 15) and at times is quite a problem.

Congenital Talipes Equinovarus

This deformity is the most difficult type to treat and the most common, making up approximately 77 per cent of all the cases of clubfeet.

The pathologic anatomy found in the individual deformity will depend upon the attitude assumed. The soft tissues become shortened on the concave side and lengthened on the convex side of the foot and the bones become molded and altered; the astragalus and os calcis show striking changes. The structures most resistant to correction in the foot of the infant are the plantar fascia and the ligaments that bind the navicular, os calcis and internal malleolus to one another. Therefore it is obvious that the early case is less resistant, becoming more resistant to corrections as the child grows older. In the older case, the astragalus becomes thicker at its external than at its internal border, and is somewhat wedge-shaped and plantar-flexed. The os calcis assumes an attitude of plantar flexion and the scaphoid is drawn inward and upward, sometimes articulating with the inner part of the head of the astragalus. All of the other bones of the foot enter to some degree into the deformity.

Clinical Picture. The equinovarus deformity (Fig. 406) is obvious. The sole of the foot is twisted inward and downward, but until the stresses and strains of weight bearing give rise to pain and fatigue no symptoms are present.

Treatment. The earlier the treatment can begin, the better. During the first few weeks of life, before the skin can tolerate adhesive strapping or plaster of Paris, the foot can be gently and regularly stretched toward the corrected attitude; that is, into an attitude of valgus and then dorsiflexion. Since after the first month the child can usually tolerate plaster of Paris, a light plaster casing should be applied. The deformities in equinovarus are threefold: (1) the varus deformity of the fore-





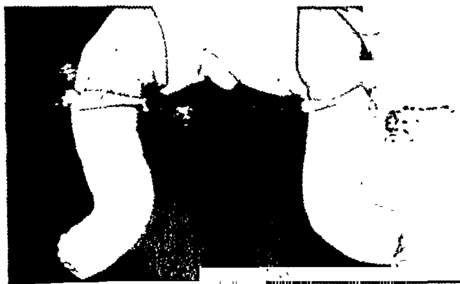


FIGURE 406. Congenital equinovarus deformity of both feet. *Top*, anterior view before treatment; *center*, posterior view before treatment; *bottom*, gradual correction by successive plasters, slowly overcoming de-formities (see Fig. 409).

foot, (2) the inversion of the heel and (3) the equinus deformity (Fig. 407); the foot must be corrected in this order.

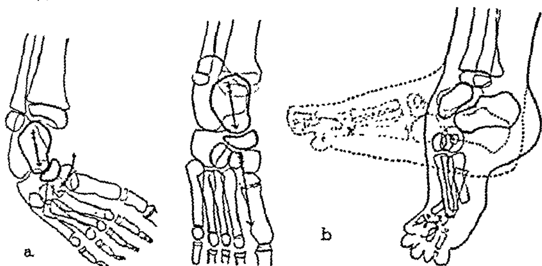


FIGURE 407. Threefold deformities of congenital equinovarus in the order in which they should be corrected. (*a*) Tracings made from roentgenograms of the right foot of a 7-year-old girl, before and after correction of clubfoot deformity by plaster casts and wedgings. The roentgenogram made before treatment shows that the weight thrust of the body coming down the tibia is transmitted forward through the astragalus, strikes obliquely on the side of the navicular, and pushes the forefoot around in adduction. When the adduction deformity of the forefoot has been completely corrected, this weight thrust is transmitted straight forward from the astragalus through the navicular to the toes, as shown in the tracing of the roentgenogram made after correction of the forefoot in adduction. If the wedging of the forefoot in abduction is stopped before the navicular is directly in front of the head of the astragalus, the deformity will recur when weight bearing is permitted, because the weight thrust will fall obliquely on the navicular. (*b*) Tracings of superimposed roentgenograms of the foot of a 4-year-old boy, before and after correction by plaster casts and wedgings. The astragalus has been forced back under the tibia, and the os calcis has been drawn forward under the astragalus. The forefoot equinus and ankle equinus have both been corrected. (Courtesy of Dr. J. H. Kite.)

A *photograph* and *roentgenogram* of the foot are helpful records before beginning treatment. The latter will show clearly the relationship of the small bones to one another and many times will indicate a delay in the ossification centers of the foot.

The first stage will be to correct the forefoot deformity (metatarsus varus), so that the scaphoid lies in its normal position in relation to the head of the astragalus. In the second stage of the treatment, that is, correction of the inversion of the heel, the roentgenogram is invaluable to show the positions of the astragalus and os calcis to one another Not until these two component parts of the deformity have been corrected should one attempt to treat the equinus. Failure to do this frequently results in the "rocker bottom" deformity (Fig. 408).



FIGURE 408. "Rocker-bottom" deformity. This is a complication of congenital equinovarus when an effort is made to correct the equinus before fully correcting the varus deformity.



FIGURE 409 Gradual correction of the equinovarus deformity by successive plasters: the metatarsus varus (*a*); the varus (*b*); the equinus (*c*)

The wedging-plaster method popularized by Kite (1930) is recommended, extending the plaster to the mid-thigh. It produces gradual painless correction of the clubfoot by repeated wedging plasters (Fig. 409). Roentgenograms are made to check the relationship of the bones so that a flexible foot with a restoration of function may be obtained. The different stages of the method are done gently. Only in the very exceptional clubfoot treated during infancy and young childhood is any surgery ever necessary. Wedging is a slow method of treatment but the results justify the effort expended. One can also obtain equally good

correction by changing the plaster weekly, molding the foot into the overcorrected position. After the foot has been molded and the plasters discarded, there is a period of supervision which should last for several years in order to guard against the tendency to recurrence. Proper treatment of clubfeet is so dependent upon complete familiarity with plaster of Paris technic that *only those so trained* should attempt to treat this deformity.



FIGURE 410. Dennis-Browne splint attached to feet by adhesive plaster.

Various types of splints and braces have very little place in the treatment of congenital clubfeet, with the exception of the Dennis-Browne splint (Fig. 410), and its use should be largely confined to treating *infants under 1 year of age*. In most infants and all older children, plaster of Paris is by far the best medium to correct the deformity slowly and properly. Usually the commercial type of clubfoot shoe is to be condemned rather than recommended; if treatment has succeeded in restoring the form and function of the foot these adjuvants will be unnecessary, and if the deformity is not corrected the various types of shoes and braces are simply supportive and not corrective appliances. Special emphasis must be placed upon full over-

correction of the deformity. Only after this are walking and muscle re-education of value. Then and only then are outer border shoe wedges, ⅛ to ¼ inch, of value.

In the clubfoot which was not corrected in early childhood, or in the occasionally resistant recurring clubfoot of children 8 to 10 years of age, a subastragalar arthrodesis, a wedge osteotomy, or sometimes even an astragalectomy may be of value but these operations should not be done at an early age. Before the child is 8 years of age operations only on the contracted soft tissues are desirable.

Other Forms of Congenital Talipes

The other forms of congenital talipes, such as *talipes equinus, talipes calcaneus, talipes varus* and *talipes valgus* are not seen frequently, and although the treatment is simpler, it follows the same general principle of slowly overcorrecting the deformity by the use of plaster of Paris and continuing with stretching exercises to retain the mobility of the foot.

Metatarsus Varus (Metatarsus Adductus)

When metatarsus varus or adductus (Fig. 411) alone occurs, i.e., an adduction of the forefoot at the tarsometatarsal joint, the patient walks with a *pigeon-toe gait.* However, it must be remembered that this same gait may be produced by other conditions. Careful examination of the leg and hip must be routinely included, for a longitudinal twist of the tibia or an internal rotation at the hip from soft tissue contracture can simulate the foot deformity. Many children learn to sit with the thighs internally rotated. Stretching of these contracted soft tissues by forcing the hips into external rotation by daily exercises or changing their sitting pattern into a cross-legged one may be necessary. If the intoeing is due to the tibial twist an osteotomy of the tibia has occasionally been done.

In those metatarsus varus cases in which the deformity is solely in the foot, successive plaster boots gradually overcorrecting the foot deformity can be depended upon to achieve correction in infancy and early childhood In the older child, beyond the age of 8, a wedge-shaped osteotomy on the outer border of the foot is occasionally necessary. However, after any correction, an outer border shoe wedge, with the anterior, outer one-fourth of the sole raised ⅛ or ¼ inch, should be worn for a few months. Even transposing the shoes for a short period after correction is useful.



FIGURE 411. Metatarsus varus deformity and congenital anomalies of the first and second metatarsal bones.

Overlapping Little Toe

Varying degrees of this deformity are frequently seen, and in the uncorrected foot the little toe often becomes irritated by the shoe rubbing which produces a tender callus. In the adult the shape of the toe becomes markedly altered; the little toe becomes flattened, flexed or overlying the fourth toe. The deformity is usually bilateral.

Treatment. In the very mild cases in infancy, simple stretching of the contracted soft tissues on the dorsum of the foot, especially the extensor tendon, may correct the deformity. In older children and adults, an operation is the method of choice. The extensor tendon is divided at its insertion and transplanted into the shaft of the fifth metatarsal, by a drill hole just proximal to the head of the bone, followed by division of the contracted dorsal capsule and stretching. The toe is thoroughly stretched and held a few weeks in the plantar-flexed position in plaster. This gives a good functional and cosmetic result (Fig. 412). In very severe cases in adult life, amputation of the toe and oblique osteotomy of the fifth metatarsal is the method of

choice, as the foot is thereby made narrower and the patient is relieved of further annoyance.



FIGURE 412 (*a*) Congenital overlapping little toe. (*b*) Operative correction

Supernumerary Toes (Polydactylism)

This congenital anomaly is not uncommon, and is often bilateral (Fig. 413). Usually the extra toe is merely a useless appendage, but occasionally it is a normally developed and functioning toe. Excision of the dangling appendage should be done. In the fully developed extra toe, plastic surgery with excision of one of the digits is usually desirable. For shoe fitting and cosmetic reasons the patient usually desires surgery. In all cases with supernumerary toes a roentgenogram (Fig. 414) should be taken of the foot, for other bones may have congenital anomalies which require surgery.



FIGURE 413. Supernumerary toes

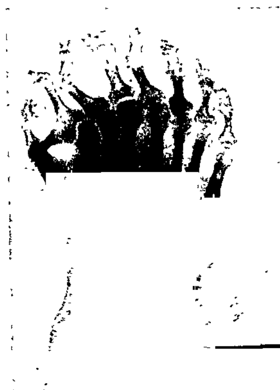


FIGURE 414. Polydactylism. This is a rare congenital anomaly.

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15

Neuromuscular Disabilities

INTRODUCTION

Before considering the various problems of neuromuscular disorders, it is well to review the mechanisms of normal motor control. A multitude of actions occur without conscious awareness, since behavior patterns have become almost automatic by the combination of reflex activity with varying degrees of voluntary modification. To perform normally, the individual must possess adequate function of the brain and spinal cord, and the effector organs in the trunk and extremities must be capable of carrying out the necessary ranges of movement with effective strength and co-ordination.

The activities of daily living represent the complex integration of varied movements of the multi-jointed skeletal system supported by ligaments and activated by muscles. The effective lever arms through which the muscles act vary continuously with changing position of the part. Yet relatively constant movements are produced against resistance regardless of the angular position of the articulating segments. The changing lengths of lever arms are offset by changes in the ability of muscles to develop torques about the joints. Hence there is a compensatory relationship between the geometric arrangement of the lever and the physiology of muscular contraction.

Human locomotion has been analyzed in detail and the results emphasize the essential interdependence of the several parts of the trunk and extremities. The muscles act not as isolated movers of a segment but as performers of a whole motion pattern (Steindler, 1925). They may be classified as stabilizers, accelerators, and decelators of the segments. Locomotion is essentially a "push-pull" mechanism

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anatomy of the various muscles which make possible the essential elements of grasping and pinching. Many other investigators, including MacKenzie (1921), Steindler (1939) and Bunnell (1956), have demonstrated the control of joint motions by muscles which stabilize the proximal joints (elbow and wrist) so that other muscles can effectively activate the distal joints (metacarpals and fingers). The length of individual muscle fibers and the excursion of the muscle-tendon complex have been measured and related to the functional capacity of the various muscles. Synergism of muscles, i.e., the wrist extensors and finger flexors, has been found to dominate certain functional patterns while other groups (wrist flexors and extensors) moderate the tension during the varying arcs of movement of the involved joints.

It is obvious from the preceding brief summary that the problems of neuromuscular disorders must be approached from a dynamic physiologic viewpoint. Deformity of bones or limitation of joint motions by contracture inevitably distorts the aforementioned leverage systems. Paralysis of muscles adversely affects not only the mechanics of motion but also the synergistic control of the trunk and extremities. The efficiency of all motor activity is ultimately dependent upon voluntary and reflex control and, although the peripheral apparatus may be intact, the lack of co-ordination and discrimination may render it useless.

DISEASES OF THE CENTRAL NERVOUS SYSTEM

Acute Anterior Poliomyelitis (Infantile Paralysis)

Incidence. Acute anterior poliomyelitis (infantile paralysis) is a communicable infectious disease caused by at least three groups of filtrable viruses, which have an especial affinity for the central motor nervous system. The disease has been with us for many centuries though not clearly recognized until about the middle of the last century, when Heine in 1840 published a description of poliomyelitis. It most frequently affects young children in the warm summer months, but may occur at any age, and during epidemics of this disease about 25 per cent of those affected are individuals over 15 years of age. It also occurs at any season of the year and in any climate. Only a fraction of the total cases are characterized by flaccid paralysis, the great majority being "abortive" or nonparalytic types. Many of these abortive cases leave the patient with undetermined weakness and follow-up care is needed. Since 1957, the year of the transition of those attacked by the

wherein the balance of the body is nearly lost and regained alternately. The upward and forward thrust of the calf muscles pushes the body upward and the erector spinae elevate the pelvis. The adductors act in relation to the lateral rotation of the thigh at push-off. The foot is dorsiflexed by the pretibial group of muscles as the leg starts to swing. In order to accelerate the leg during the swing phase, the quadriceps contract and just prior to heel contact, the hamstrings act, providing rapid deceleration of the leg with stabilization of the knee when the heel is placed. Simultaneously the pretibial muscles decelarate foot-slap. Also the knee must then be stabilized by the quadriceps to decelerate flexion during the energy-absorbing phase. As the weight falls on the foot, the pelvis is stabilized by the combined action of the adductors and abductors, and contraction of the abductors and erector spinae prevent lateral shift of the trunk and a list toward the opposite side. The gluteus maximus muscle counteracts a tendency of the limb to rotate internally at the midstance phase. The opposite heel then contacts the ground and the cycle is repeated

The upper extremity presents different considerations, having no function of weight bearing, but by central co-ordination serving a related purpose in balance and locomotion. When the lower limbs are deformed or paralyzed crutch-walking may then become the only practical means of ambulation. The interdependence of the parts to subserve the needs of the whole being is dramatically demonstrated. The form of the upper limbs has become adapted to the demands of mobility, versatility and dexterity. Again nature has provided a marvelous concatenation of levers with superb power and control. This mechanical system is dependent upon the same essential principles of joint and muscular dynamics as the lower extremities but becomes superior by virtue of the end organ, the hand.

In man the hand with an opposable thumb sets him apart from other primates to manifest the superiority of his brain. The bilateral amputee soon becomes acutely aware of his great deficit and man has not yet been able to contrive a totally successful duplicate replacement. Aside from the purely mechanical problems of providing delicate, rapid movements and great holding strength, the need remains for sensation in all its modalities, including fine touch and object perception.

The over-all function of the upper extremity and hand has been the subject of intensive study for many decades. Duchenne's observations (Duchenne, 1949) are outstanding contributions to the functional

anterior horn cells in the cervical and lumbar region are especially susceptible to the virus.

It is doubtful that edema alone plays a dominant role in the production of paralysis; certainly severe paralysis can occur without evidence of edema. The distribution of the muscle impairment may be widely scattered and not necessarily symmetrical, although the lower extremities are routinely more frequently involved than the trunk or upper extremities.

In the gastrointestinal tract Peyer's patches are often enlarged, hemorrhagic and edematous, as are also the adjacent mesenteric lymph nodes. Hyperplasia of the tonsils, pharyngeal lymph structures and the spleen is also seen at necropsy.

Clinical Picture. The incubation period is often stated to be from 5 to 14 days, though it should be remembered that the poliomyelitis virus is capable of great variability in behavior. The acute stage may last 4 to 8 weeks. It is most contagious during the first week or two of the infection. Patients have been reported who have had more than one attack, although it is thought that having the disease once with one strain of the virus confers complete and permanent immunity from a recurrence from that strain. The stage of convalescence lasts from several months to a year. The final or chronic stage in which very little, if any, muscle recovery occurs is more especially the period in which orthopaedic appliances and operations must be used, although protective mechanical measures should be employed from the onset in the paralytic cases.

The disease is usually ushered in by malaise, loss of appetite, sore throat, gastrointestinal disturbances, fever, headache and drowsiness. There are two distinct pictures: (1) the abortive type, a nonspecific illness with return to a normal temperature within a few days, constituting the great majority of poliomyelitis cases; and (2) the paralytic or severe type, which is an acute illness of longer duration. There may be nausea or vomiting, headache, loss of appetite and lassitude. Very early in the disease stiffness of the neck or back may occur with muscle pain and soreness, followed by weakness or paralysis.

The great majority of the abortive cases remain undiagnosed, though during epidemics the disease should be suspected whenever in the summer months a child is affected with malaise, and shows gastrointestinal and mild respiratory symptoms. An increased intraspinal pressure and pleocytosis are the most specific of the early laboratory signs, with

disease, the number of cases has dramatically decreased, for there has been an 85 per cent drop from the average of the five years (1950 to 1954) immediately preceding the mass use of the Salk vaccine. The annual number of cases reported from 1950 through 1954 was 58,727, whereas in 1957 only 5,894 cases were reported in the United States Public Health Service. Of this number of cases, almost half were paralytic. There have been no full scale poliomyelitis epidemics in areas adequately covered by Salk vaccine, but, unfortunately, there are far too many cases, due to apathy on the part of the public, that could have been prevented by the use of the Salk vaccine. The disease may never be completely eradicated from the world. It is too early to be too dogmatic regarding this but the statistics have been thus far so fantastically lowered by the use of the Salk vaccine that poliomyelitis bids fair to take its place with the other rare diseases, such as diphtheria, small-pox, etc., in the civilized countries.

The tremendous opportunity we have to eradicate this disease by immunization must not lessen the struggle toward caring for those patients with involvement of respiration, extremity and trunk.

Routes of Infection. The virus of poliomyelitis has an especial affinity for the anterior horn cells of the spinal cord, although both the pons and the medulla may be affected. The disease is apparently introduced into the body through the alimentary tract and the upper respiratory passages. The viruses, of which there are three strains, have been found in the stools even before they have been established by other methods and are capable of prolonged activity. The virus has been recovered from the feces two weeks before the clinical development of poliomylities.

Pathology. In both the paralytic and nonparalytic (abortive) types the great majority of poliomyelitic patients show lesions in the brain. Certain areas such as the brain stem and the motor area of the cortex are frequently and severely involved, whereas the entire cerebral cortex and the cerebellar cortex are rarely involved.

Among the earliest visible evidences of virus activity in an infected spinal cord are mild inflammatory changes. The polymorphonuclear and mononuclear cells are increased, at first in the perivascular tissue and shortly thereafter in the gray matter; this change is most marked in the anterior horn cells. These inflammatory changes are variable but when severe are usually associated with extensive nerve cell destruction. The virus probably spreads by way of the axon. The large

paralyzed permanently. The affected limb becomes colder to palpation. Objective sensation is not disturbed, and the bladder and rectum are not permanently affected.

Included in this chapter is a muscle examination chart (see p. 648) and in Chapter 1 are sets of figures selected from the excellent manual of Daniels, Williams, and Worthingham (1956) which are self-descriptive.

In the chronic stage the permanent deformities have developed. The fitting of the patient with braces and the employment of the various types of standard orthopaedic operations are specialized problems for the orthopaedic surgeon.

Prognosis. The prognosis must always be guarded but can be said to be favorable in the great majority of cases. It must depend not only upon the extent of the paralysis but also upon the early care the patient receives. The bulbar type affecting deglutition and respiration is far more serious for life than those in which simply the trunk or extremities are involved. As a rule the extent of the paralysis appears very much greater in its early stages, but there is always a tendency for recovery to occur to some degree. In general, the prognosis for recovery of upper extremity and trunk involvement is better than in those cases in which the lower extremities alone are involved.

In the acute stage, death may occur from cardiac failure if the medulla oblongata is implicated. A fatal type of bronchopneumonia also may occur if the muscles of respiration are paralyzed. Recovery usually follows if the patient survives the acute stage, but different degrees of muscular paralysis generally persist. Patients who have only a mild attack of the disease without paralysis recover completely.

Muscles showing the complete electric reactions of degeneration do not get back all of their function. Sometimes, individual muscles are only partly paralyzed and still keep their faradic irritability; subsequently partial recovery of function may then take place.

Treatment. Treatment may be divided into the prophylactic care of the patient and care in the acute, convalescent and chronic stages of the disease, and finally rehabilitation of the patient.

Prophylactic Care. At the present time, the Salk vaccine is readily available and should be given to the population. Research is continuing to improve its efficacy. A combined vaccine with the Salk is being used for the common childhood diseases and much work is in progress toward using attenuated live vaccine. With the drop in poliomyelitis being so dramatic during the past few years due to the vaccine, the

a polymorphonuclear increase which changes early to a mononuclear lymphocytosis. When the disease is suspected, the child should be treated as though he had poliomyelitis. The early signs and symptoms may closely simulate several infectious diseases, and it is only after the paralysis has appeared that the diagnosis is usually made. Occasionally the symptoms in the paralytic cases are so mild that only when the child begins to bear weight are the awkwardness and muscle weakness detected. The tendon reflexes are usually diminished or lost and there are alterations of the electric reactions. Muscle sensitiveness may be accompanied by some fibrillary twitching of the muscles. About the second day, rarely after the first week, muscle paralysis may be noted, which is usually of the flaccid type. Involvement of the pons or medulla produces respiratory embarrassment, and such cases are the most serious type. When the virus attacks the brain stem or extends upward, a spastic type of paralysis may result. As the paralysis may be widespread, great care must be taken in the initial examination to determine the regions and localities involved as well as the individual muscle groups affected. The severity and the amount of the paralysis can be determined by the electric reactions, but this should not be done during the acute phase. Those cases with abdominal or spinal involvement show a tendency to develop paralytic scolioses later. Rapidly following the paralysis, muscle atrophy appears; in cases with permanent paralysis, the growth of the extremity involved is retarded. Severe paralyses are also apt to result in severe contractures, although appropriate physical therapy lessens this tendency.

After the acute stage, muscle sensitiveness and general constitutional symptoms subside and the weakened muscles begin to show varying degrees of recovery. The convalescent stage is a period in which a prognosis regarding the extent of muscle recovery can often be made. Contractures and deformities of the paralyzed limbs develop in the acute and convalescent stages unless active and controlled movement of the joints is instituted early. In the convalescent stage periodic muscle examinations must be made in order to determine accurately the progress of the case and the rate of recovery.

In the typical case, after the child has fully or in part recovered from the general infection, there is weakness in the muscles of one or both lower limbs, and sometimes of the upper limbs or the trunk. Pain is caused by movements of the affected limbs, the muscles may be sore, and the skin sometimes is hyperesthetic. Recovery in part generally occurs within a few weeks, but some muscles often remain

movement of the part affected. However, *vigorous* hot packings in the early acute febrile stage are not advisable.

Local heat has been employed in one form or another for some years (Lovett and Jones, 1927); many orthopaedic surgeons have advocated early movement for these joints within the limits of painlessness in therapeutic pools or warm water to hasten recovery (Lowman, 1937). If the limbs are supported properly and exercise and muscle re-education instituted as soon as *the soreness will permit,* the percentage of joint contractures can be greatly lessened and the patient rendered both more comfortable and happier; *however, in the acute stage, rest and not forced activity must be insisted upon.* At the end of about four weeks the acute stage has usually passed or lessened sufficiently to permit movement of the joints actively in a pool or passively by a trained physical therapist.

In cases of respiratory embarrassment prolonged administration of artificial respiration by means of a respirator is indicated.

Convalescent Stage. In the convalescent stage the weakened muscles may have recovered some of their tone; this should be the period of muscle re-education, for a good deal more activity can be permitted than in the previous stage. Here, however, standing or motions which put too great a burden upon the already weakened muscles, such as exercising them against gravity, must be prescribed for the individual patient and not routinely employed. The patient can be allowed an increasing amount of liberty in bed, and during the latter part of the convalescent stage may be allowed to sit up unless there is a marked imbalance of muscle function in either the spinal or abdominal muscles. When these groups are affected, the upright position must be permitted very slowly in order to prevent or minimize the scoliosis that may develop.

Approximately one year after onset, during which time judicious exercises for muscle training along with electric stimulation to impaired muscles have been continued and proper support worn, a varying percentage of the muscle impairment will have recovered. Those muscles unimproved by this time can usually be regarded as permanently paralyzed.

Chronic Stage. The chronic or late stage is the period in which an evaluation must be made of the mechanical, social and economic problems presented, and a rehabilitation program outlined. The patient can now be fitted with permanent, well-fitting braces, or considered a candidate for one or more of the many useful and standard ortho-

immunizing program toward prophylaxis for all under 40 years of age should be mandatory. It would guarantee against epidemics of paralytic poliomyelitis if and when universal vaccination is attained.

Acute Stage. The treatment in the acute stage of infantile paralysis is most important, for it may affect to a great extent the future disability of the patient. In the acute stage, when there is marked sensitiveness of the muscle groups, it is most important to keep the patient quiet, allowing him to assume whatever position is comfortable. As the tenderness and pain subside the patient is encouraged to lie flat on a firm mattress, and with the lower limbs in a good position for weight bearing. A well-fitting, light plaster of Paris shell or light aluminum splint can be worn, keeping the feet at right angles to the legs and the knees slightly bent.

Although the distribution of the paralysis varies greatly and the percentage of muscle recovery is largely dependent upon this, the treatment should also be directed toward the general systemic care as well as the local protection of the sensitive muscles. The physician must also spend time educating the family and the patient against hysteria and emotional outbursts so that neither becomes unnecessarily frightened and apprehensive. Every effort should be made to record the status of the affected muscle groups early in the disease as a record for future muscle function recovery. The soreness and pain on movement may make such an examination incomplete, but some valuable information can be obtained and recorded. A more detailed muscle chart (p. 648) can be made at varying periods in the convalescent stage and the residual paralyses carefully evaluated in the chronic stage.

A general bland diet should be employed. The patient should maintain the recumbent attitude on a firm mattress while the feet are supported at right angles to the leg, the patellae and toes pointing upward to prevent the lower extremities from falling into the attitude of outward rotation. The arms should be placed in the most comfortable attitude as regards muscle sensitiveness; frequently this is in an abducted attitude by means of the airplane splint. No pillows should be employed under the head. A few years ago a great deal of interest was manifested in the Kenny (1941) method of treatment, i.e., the periodic application of very hot packs to the sore and spastic muscles during the extremely sensitive stage These packs make the patient more comfortable in the great majority of cases. The packs are applied over the bellies of the muscles, this treatment was combined with early

LEFT										RIGHT
					Examiner's Initials					
					Date					
SCAPULA					Abductor—Serratus anterior					SCAPULA
					Adductor—middle trapezius					
					Adductors—Rhomboids					
					Elevators					
					Depressor					
SHOULDER					Flexors					SHOULDER
					Extensors					
					Abductors					
					Horizontal Abductor					
					Horizontal Adductor					
					External rotators					
					Internal rotators					
ELBOW					Flexors					ELBOW
					Extensors					
FOREARM					Supinators					FOREARM
					Pronators					
WRIST					Flexor—radial deviation					WRIST
					Flexor—ulnar deviation					
					Extensors—radial deviation					
					Extensor—ulnar deviation					
FINGERS					Flexors—metacarpophalangeal					FINGERS
					Extensors—metacarpophalangeal					
					Flexor—proximal interphalangeal					
					Flexor—distal interphalangeal					
					Abductors					
					Adductors					
					Opponens—5th finger					
THUMB					Opponens					THUMB
					Flexor—metacarpophalangeal					
					Extensor—metacarpophalangeal					
					Flexor—interphalangeal					
					Extensor—interphalangeal					
					Abductors					
					Adductor					
					MEASUREMENTS					
CHEST					Inspiration					CHEST
					Expiration					
ABDOMEN					Umbilicus to Ant. Sup. Spine					ABDOMEN
LOWER EXTREMITY					Circumference—mid calf					LOWER EXTREMITY
					Circumference—mid thigh					
					Ant. Sup. spine to int. malleolus					
					Umbilicus to internal malleolus					

Cannot walk Date ______ Walks with crutches Date ______

Stands Date ______ Walks with canes Date ______

Walks with braces Date ______ Walks unaided Date ______

Walks with corset Date ______ Climbs stairs Date ______

Other Apparatus ______

Scoliosis and other deformities ______

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FIGURE 415 *continued.* Muscle examination chart.

MUSCLE EXAMINATION

Patient's Name ______________________________ Chart No. __________
Date of Birth ______________ Name of Institution ______________
Date of Onset ______________ Attending Physician ______________ M D
Diagnosis:

LEFT										RIGHT
					Examiner's Initials					
					Date					
NECK					Flexors					NECK
					Extensors					
TRUNK					Flexor					TRUNK
					Extensors—thoracic					
					Extensors—lumbar					
					R. ext. obl. / L. int. obl. } Rotators { L. ext. obl / R. int. obl.					
					Elevation of pelvis					
HIP					Flexors					HIP
					Extensors					
					Abductor					
					Adductors					
					External Rotators					
					Internal Rotators					
					Sartorius					
					Tensor fasciae latae					
KNEE					Flexor—outer hamstring					KNEE
					Flexors—inner hamstrings					
					Extensors					
ANKLE					Plantar-flexors—Gastroc. & Soleus					ANKLE
					Plantar-flexor—Soleus					
FOOT					Invertor—Anterior tibial					FOOT
					Invertor—Posterior tibial					
					Evertor—Peroneus brevis					
					Evertor—Peroneus longus					
TOES (4 lateral)					Flexors—metatarsophalangeal					TOES (4 lateral)
					Extensors—metatarsophalangeal					
					Flexor—proximal interphalangeal					
					Flexor—distal interphalangeal					
					Abductors					
					Adductors					
HALLUX					Flexor—metatarsophalangeal					HALLUX
					Flexor—interphalangeal					
					Extensor—interphalangeal					

Additional Data
Face ______________________________
Speech ______________________________
Swallowing ______________________________
Diaphragm ______________________________
Intercostals ______________________________

KEY

100%	5	N	Normal	Complete range of motion against gravity with full resistance.
75%	4	G	Good*	Complete range of motion against gravity with some resistance.
50%	3	F	Fair*	Complete range of motion against gravity
25%	2	P	Poor*	Complete range of motion with gravity eliminated
10%	1	T	Trace	Evidence of slight contractility. No joint motion.
0	0	0	Zero	No evidence of contractility.
	S or SS		Spasm	Spasm or severe spasm.
	C or CC		Contracture	Contracture or severe contracture

* Muscle Spasm or contracture may limit range of motion. A question mark should be placed after the grading of a movement that is incomplete from this cause.

FIGURE 415 Muscle examination chart.

completely accurate as some others, its simplicity and general ease of application have made it widely adopted.

The examiner, of course, must be familiar with the gross anatomy of the individual muscles as well as their function in order to test the muscular system intelligently and accurately. The patients with residual paralyses frequently develop so-called "trick movements," and unless the examiner is careful to test the function of the individual muscle groups he may be led astray regarding the true muscle function. For example, with a paralyzed or weak deltoid muscle the patient may learn to rotate the arm externally and then abduct it by the power of the long head of the biceps. This gives a jerky type of movement but allows the arm to be partly abducted from the side even with completely paralyzed deltoid and supraspinatus muscles. At the hip, with paralysis of gluteus minimus and medius, the tensor fasciae latae may act as an abductor to a remarkable degree. At the knee the patient with a completely paralyzed quadriceps muscle may be able to lock his knee on standing and walk surprisingly well by placing his foot into slight equinus. These and many other trick movements which the patient learns permit him to utilize the muscles that are active and partially compensate for the loss of certain muscle groups. The patient should be studied and these maneuvers understood by the examiner if he wishes to avoid the pitfalls and complexities of paralytic deformities. The pattern of activity may be a very complicated one. Too hasty decision regarding operative correction of a local deformity may give the patient a cosmetic improvement but, on the other hand, his activity and his physical independence may be much interfered with by injudicious operative procedures.

Growth and development of our body structure only proceeds normally when function is normal. Therefore, with muscle imbalance we not only develop deformities and contractures through muscle paralyses, but the bones and joints also undergo striking accommodative changes.

Curvature of the spine (Fig. 416) as the result of infantile paralysis is frequently observed. There are many ways in which a paralytic scoliosis may be produced; the muscle power of the back as well as the strength in the abdominal muscles may cause a curvature to develop. Many times in these paralytic patients, involvement of one or both lower extremities produces a difference in leg lengths and an obliquity to the pelvis, which result in spinal curvature. A careful muscle check to determine the groups of muscles involved must be made, and

paedic operations. In general, the *orthopaedic surgeon operates in order to permit the patient to discard braces.*

The aim of treatment in the chronic stage whenever the child or adult is physically handicapped becomes one of *considering the patient as a whole.* One must consider *proper vocational guidance* as the goal so that economic independence as far as possible can be attained. A sympathetic understanding of the patient's personality helps a great deal in directing the long drawn out program of rehabilitation. The abilities and disabilities of the crippled child or adult must be carefully studied and often the social worker, psychologist and members of the patient's family can assist a great deal in these problems.

A careful, systematic *muscular examination* is necessary to determine the degree of deformity that is present or will be present in the future, based upon the inability of the paralyzed groups of muscles to maintain balance at the joints. When muscle power permits, the patient should be studied while walking in order that the observer may note the gait, the contractures, the muscle power or muscle weakness as well as the underdevelopment of the bones and soft tissues. Any deformities that the paralyses have produced should be noted, and these can best be observed while the patient is weight bearing, although this is not always physically possible. All this must be done in a good light and as far as feasible with the patient completely undressed.

The table on which the patient is examined should be waist-high, wide, and have a smooth surface which is kept powdered during the muscle movements in order to avoid as much friction as possible.

A careful written record should be made at the time of the physical examination, and the muscle function tests, as demonstrated in Chapter 1, should be used, recording the muscle power on a chart somewhat similar to the one given in this chapter (Fig. 415). Many muscle charts have been carefully worked out following in general the formula established by Lovett and his associates in 1916. Appended is the Muscle Examination Chart supplied by the National Foundation. In brief, the muscle that is without any active power is classified as O, that with a flicker of power, as a trace, T; the muscle that can function only when gravity is eliminated is classed as poor, P; while the muscle that can carry its normal load against gravity is graded as fair, F, the muscle acting against normal resistance as well as against gravity is classed as good, G, and the normal muscle is classified as N. This plan is probably the simplest that has been worked out; while it is not so



FIGURE 417. "Winged scapula." This is due to paralysis of serratus anterior muscle on the left.



FIGURE 418. Right deltoid paralysis. Note typical muscle atrophy and inability to raise arm.

in addition roentgenograms of the entire spine taken. Undoubtedly too early standing or attempts at weight bearing in the convalescent stage of infantile paralysis have been responsible for the development of a number of spinal curvatures. In some instances a simple type of back



FIGURE 416. Paralytic scoliosis, showing telescopic action of the spine. (*a*) Sitting; (*b*) with longitudinal traction.

support is of definite value. In others, some type of muscle transposition or equalization of the leg length (see Chapter 1) alone in the lower extremities may be an aid in lessening the lateral curvature of the spine. Contractures producing a pelvic obliquity require surgery to aid in improving the scoliosis. In the carefully selected case an arthrodesis of the spine is advisable for paralytic scoliosis.

In the upper extremities there may be complete or partial inability to demonstrate full function at the shoulder (Fig. 417); the abductor muscles especially may show weakness and atrophy (Fig. 418). Other muscle groups which produce adduction, internal or external rotation as well as circumduction should be tested. At the elbow, extension and flexion as well as pronation and supination of the forearm should be checked, and also the finer movements in dexterity at the wrists and fingers.

In the lower extremities, at the hips the four major movements of flexion, extension, abduction and adduction as well as those of rotation and circumduction should be tested both with and without the forces of gravity, while the contractures which occasionally occur should be noted and recorded if they are present. At the knee the

As a rule the orthopaedic surgeon operates in order to permit this type of patient to discard braces, or at least to lessen the number that he is wearing. There are a certain number of patients, however, who must be made to realize that a continuance of brace wearing is much



FIGURE 420. Paralytic drooping of forefoot. This is due to weakness of the dorsiflexor muscles, producing a cavus of the foot.

more satisfactory than any operative procedure. This may be due to their disability being widespread or to the complexity of the pattern of their paralysis.

Operations. An operation or series of operations may allow the patient to discontinue the use of braces and crutches. The mature judgment and experience of the orthopaedic surgeon are of inestimable value as there are many operative methods at his disposal in the rehabilitation of the paralytic cripple. Proper planning of the operation or operations necessary, in their order of importance in the particular case, not only requires a thorough knowledge of the proven types of operations for particular deformities, but also requires a knowledge of the patient's opinion regarding which deformity is, to him, most dis-

muscles producing flexion and extension should be tested. Genu recurvatum (Fig. 419) is produced by weakness or paralysis of the muscles behind the knee. At the ankle and foot the complicated series of movements producing flexion, extension, inversion and eversion should be actively and passively demonstrated. Figure 420 shows a common paralytic deformity of the foot.



FIGURE 419. Paralytic recurvatum. This condition may follow weakness or paralysis of the hamstring or calf group of muscles.

Rehabilitation Treatment. *Exercises.* Muscle re-education exercises have a very definite place even in cases in which the chronic stage has been reached. A remarkable improvement in muscle function may sometimes be obtained by intelligent guidance in such exercises. With very weak and poor muscles the patient may show marked improvement, but this does not mean that complete recovery in muscle function can be expected or obtained even under the most careful and meticulous methods of muscle training. There is a limit to what the patient may expect. Various deformities occur as the result of imbalance and offer a fruitful field for rehabilitation by operative measures.

Braces. A certain number of patients must continue to wear braces.

of the knee, and yet an internal or external hamstring transplant is a very valuable operation.

(2) *Fasciotomies, tenotomies and capsulotomies.* These are useful operations. They are, in brief, divisions of the contracted fasciae, tendons or capsule and are useful in overcoming these soft tissue contractures. Tenotomies are particularly worthwhile in cases of paralytic equinus in which the short Achilles tendon is resistant to stretching. Fasciotomies are useful with certain types of contracted fascia, such as clawfeet. Capsulotomy or division of the posterior capsule is used in certain resistant knee-flexion contractures.

(3) *Bone stabilization operations.* These include a great number of surgical procedures done on the skeletal system, such as the various types of arthrodeses on the shoulder, hip, knee, foot or other joint. These operations generally should be delayed until the child is 9 or 10 years of age. They permit the patient to utilize the remaining active muscles that are not involved in infantile paralysis to much better advantage, and even sometimes to discard braces. These procedures are particularly useful in certain paralytic deformities of the feet, to correct valgus, varus, drop foot, equinus or a combination of these deformities. Following the bone stabilizing operations, muscle transpositions again have a useful place in the rehabilitation of the paralytic child or adult.

To restore the normal relations between the astragalus and calcaneus in the paralytic at an earlier age than it is possible to do with a subastragalar arthrodesis, Grice (1952) has published what he calls an extra-articular arthrodesis of the subastragalar joint. This consists of using tibial bone grafts placed in the sinus tarsi as shown in Figure 421. If tendon transplantations are necessary to correct muscle imbalance, these can be done at the same time, or preferably in stages.

(4) *Astragalectomy.* Astragalectomy with backward displacement of the foot was originally devised by Whitman only for paralytic calcaneovalgus (Fig. 422). It is a most satisfactory operation when done for this condition if close attention is paid to the indications, technical operative details and follow-up. This operation is rarely done today.

Campbell's *Operative Orthopaedics* gives detailed descriptions of operations for paralytic patients.

Chronic Anterior Poliomyelitis (Progressive Spinal Muscular Atrophy; Aran-Duchenne Type)

Progressive spinal muscular atrophy (Aran-Duchenne type of mus-

abling. The orthopaedic surgeon has at his command operations on the soft parts, which consist of tenotomies, fasciotomies and muscle transpositions, and also operations involving primarily the bony system, such as arthrodeses, epiphyseal arrest of growth, osteotomies and the various types of reconstructive procedures.

(1) *Tendon transposition.* In those who can be helped by operative measures, one of the most useful procedures is tendon transposition. This operation has a wide field of application and its success depends both upon the operative skill of the surgeon and upon the co-operation of the patient in the long period of muscle training and muscle re-education. Certain localities in the body lend themselves particularly well to a successful tendon transposition. Obviously a weak muscle that is normally weaker than its antagonist can never act so effectively as a strong muscle would normally. The old dictum of "sending a boy to do a man's work" is particularly applicable in the consideration of muscle transposition.

One of the most successful muscle transpositions is for the correction of wrist drop. This consists of transposing the active flexors of the wrist, the flexor carpi ulnaris and flexor carpi radialis muscles, into the paralyzed extensor muscles of the wrist. At this region, as in others, the muscle transposition not only partially restores the power of dorsiflexion to the wrist, but almost as important, it removes the vicious force of the strong wrist flexors and transposes them into a "power for good." This fact is also strikingly seen in the muscle transpositions at the ankle, where the evertors of the foot may be transplanted through the tendon sheath of the paralyzed anterior tibial muscle, thereby transforming the transplanted muscle or muscles into an invertor of the foot; at the same time the operation removes the normal action of eversion and frequently should be preceded by a subastragalar arthrodesis

One of the main values of muscle transposition lies in the fact that it may be utilized at an earlier age in some of these paralytic children, allowing them to be "tided over" until they have reached sufficient bone development to do some type of operation upon the bony structure of the body.

It must be remembered that in any transposition a certain amount of the power of the transposed muscle to move the joint is lost by the unphysiologic action that it must assume; this is particularly true in transposition of the biceps femoris to take over the function of a paralyzed or weak quadriceps, for the biceps femoris is normally a flexor



FIGURE 422. Heel deformity with paralytic calcaneus. The deformity occurs because of paralysis in the calf group of muscles. The whole foot and leg become smaller than the unaffected side. In part, the lack of development results from the loss of "the push" to the foot in walking.

cular atrophy) presents a progressive wasting of the muscles, caused by a slow degeneration of the anterior horn cells of the spinal cord, beginning about the thirtieth year of life. At first it may be unilateral but soon becomes bilateral. The cause is not known.

The term "chronic anterior poliomyelitis" is often used when referring to progressive spinal muscular atrophy, generally to those forms of the disease in which weakness develops before atrophy. The name "chronic anterior poliomyelitis" is likely to cause confusion when referring to the chronic stages of acute anterior poliomyelitis, which is an entirely separate disease (Cadwalader, 1932).

Pathology. There is an atrophy and slow degeneration of the anterior horn cells of the spinal cord and a corresponding loss of peripheral motor neurons. This is more apparent in the cervical region, but in some instances, the cells of the motor nuclei of the medulla oblongata are also affected. In proportion the anterior motor roots degenerate. Hemorrhages have been observed in the gray substance of the cord.

Clinical Picture. Insidious and slowly progressive muscular wasting develops, generally first affecting the small muscles of the hands, al-



FIGURE 421. Paralytic valgus of right foot *Top*, before operation *Center*, same foot immediately following Grice extra-articular arthrodesis. *Bottom*, same foot 10 months after operation, showing massive bony block.

For additional accounts of this syndrome refer to Guillain (1936), Bassoe (1938) and Dempsey *et al.* (1947).

Cerebral Palsy

In 1852 Little first drew attention to this condition. It has been given a variety of names, including *Little's disease, cerebral palsy, spastic paralysis* or *cerebral paralysis of childhood,* and according to Phelps (1946) occurs in 7 per 100,000 population per year. Disturbances of voluntary motor function, often with some degree of mental impairment, are the characteristic features.

Etiology. In all types of cerebral palsy the lesions are in the brain, and inasmuch as there are a number of unrelated causes, great variety in the types of pathology are found. Certain patients may present large cystic areas in the brain tissue or softening of the brain due to hemorrhage of an intrauterine origin. In this group will be found the largest number of mental defectives, representing cases in which little improvement may be anticipated. In other types, tears in the tentorium producing hemorrhage and damage to the cortex or to the base of the brain, particularly the basal ganglion, can be demonstrated. Cerebral palsy may also be due to embolism, thrombosis or some acute infectious disease giving rise to an encephalitis. Injury at birth is given as the cause of a large percentage of the acquired types, but it is obviously not the only causative factor. The entire entity was formerly rather loosely grouped under Little's disease, and under this term was included varying degrees of mental and physical impairment, from the drooling idiot unable to walk or stand, scarcely recognizing his surroundings, to the mild monoplegic of almost perfect mentality who walks with a scarcely perceptible limp. Great advances in the understanding of the basic pathology have been made within recent years, and more adequate care in this condition has been made possible.

Clinical Picture. Crothers and Putnam (1927), Carlson (1935), Fay (1946), Phelps (1946) and others have made notable contributions to this subject. The condition may be divided into *four main types:* the *spastics,* averaging about 40 per cent; the *athetoids,* about 30 per cent; the *ataxias,* about 15 per cent, and the *tremor and rigidity group combined,* about 15 per cent. These terms describe the most prominent clinical feature of each type, but these will overlap in the same individual; the following classification is based on the most prominent feature present, although more detailed classifications have been proposed.

though it can begin in the shoulders and upper arms. This wasting and atrophy give rise to weakness in the movements of the hands or upper limbs. Sometimes weakness is present before the development of atrophy. It usually takes a number of years before all the muscles of the upper limbs and shoulder girdle are greatly affected; following this the back muscles are affected. The lower extremities, as a rule, are not involved until quite late in the course of the disease, but it has been reported that atrophy may begin occasionally in the lower limbs. The tendon reflexes are absent or greatly diminished. Although fatigue and increasing ache in the muscles develop, acute pains apparently never occur. The electric reactions of the muscles indicate qualitative or quantitative alterations.

Prognosis. The prognosis is poor. The progression of the disease continues over long periods of years. Generally the patient dies of an intercurrent infection. However, when bulbar symptoms of this disease develop early, the patient usually dies within 2 or 3 years.

Treatment. The treatment is palliative; electricity, massage of the muscles still unaffected, limited physical activity and small doses of strychnine may be helpful, but not curative. Braces occasionally are of some benefit.

Guillain-Barré Syndrome

A disease of unknown etiology occurring in adults and producing an acute polyneuritis was described by Guillain *et al.* (1916).

The immediate prodromes vary from severe headaches and backaches to mild paresthesias of the hands and feet. The trunk, but more especially the lower limbs, develop a flaccid type of paralysis and in general the deep tendon reflexes are lost. This condition may at first be confused with poliomyelitis. The temperature in all cases has been within normal limits. The spinal fluid as a rule shows an increase in protein, but the cell count offers a distinct difference from that in poliomyelitis for it remains within normal limits.

Treatment. Various forms of therapy have little, if any effect on the clinical course of the disease. Rapid recovery is more apt to occur than in poliomyelitis. General supportive measures should be employed and when respiratory paralysis occurs, the patient should be placed in a respirator.

During the early stages of the disease absolute rest is imperative. To prevent overstretching of paralyzed muscles and contractures proper splinting should be applied.

Lesions involving the cerebellum. In these patients, some degree of *ataxia* and a loss of postural balance are present. These children are late in walking, usually have some speech defect, and dizziness and nausea are frequent complaints.

Combined types of brain damage. These lesions are found in patients with *tremors and rigidities.* Frequently these cases represent diffuse cerebral processes such as postencephalitis and multiple petechial hemorrhages. In these types there is a high degree of feeblemindedness.

Prognosis. Because of the inability of the cerebral palsy patients to make their wants and ambitions known, they rarely obtain the usual educational advantages. The primary problem is to determine the individual's degree of mental ability. When there is mental acumen, the response to treatment is sometimes amazingly successful. The desire to improve and the eagerness with which these patients try to overcome their physical handicaps is striking. It is a most difficult problem to estimate the prognosis in the individual, and here it is essential to obtain the intelligent co-operation of the parents in the long but necessary supervision and education. Improvement is slow at best and it is only with the combined efforts of the doctor, patient, parents, occupational and physical therapists, all fitting into a well-planned, long-range program, that the best results will be achieved.

The underlying cause and extent of the lesion are important factors in the *course* of the various cerebral palsies of children. The outlook for complete recovery is comparatively poor. Some residual evidence of the condition is likely to persist.

Treatment. Persistent muscle training, physical therapy, occupational therapy and speech training, with occasionally selected operative procedures, represent the keystones in the educational program.

The neglect of children with cerebral palsy in the country at large is stupendous. One must try to make them develop the highest degree of independence and normal living. The preliminary and evolutionary steps in educating these children have been lacking; therefore, the fundamentals of these acquired patterns of the normal child must be instituted in their training program.

Briefly, in a *spastic* patient, controlled motions should be established. In using surgical procedures in this type of patient, it should be remembered that the most favorable cerebral palsy patient for operation is the spastic with good mentality. Even here all operations must be combined with a well-organized physiotherapeutic follow-up care to

A determination of the mental ability of the patient is of prime importance. Because of the overflow of movements, the facial expressions will many times be a poor index to the mentality. The grimaces and muscular contractions of the facial muscles, inability to demonstrate intelligible speech and general muscular in-co-ordination may on casual examination result in a hasty and erroneous opinion regarding the true mental status. Therefore, careful and repeated examinations must be made in as quiet surroundings as possible in order to obtain anything like a fair estimate of the patient's intelligence. Phelps estimates that 68 per cent of cerebral palsy patients show a good mentality.

Pathology. *Lesions involving the cerebral cortex.* An irregular distribution of cerebral hemorrhage may produce both flaccidity and spasticity of muscles in the same extremity. The true *spastic* type presents hyperirritability and hypercontractility of a muscle when it is stretched. In the case of a spastic quadriceps muscle, attempts to flex the knee with the hamstring muscles will result in the automatic contraction of the quadriceps, blocking the effort to flex the knee, the so-called "stretch reflex." Therefore, with damage to the cerebral cortex the clinical picture is usually one of spasticity, but as the cerebral lesions may be irregularly distributed, all the muscles of the extremity may not be equally involved, and spastic, flaccid and normal muscles may be found in the same limb. The tendon reflexes are hyperactive in this type. If only one extremity is affected, it is *monoplegia;* with only one side of the body, *hemiplegia;* when only the lower extremities are affected, it is *paraplegia;* if either both upper or both lower extremities are involved, a *diplegia;* with involvement of all four extremities, a *quadriplegia.*

In lesions of the cerebral cortex, the speech center may be involved.

Lesions at the base of the brain in the basal ganglia and extrapyramidal tracts. These lesions produce the *athetoid* type of movement which is characterized by involuntary, aimless motions. The part is moved in a way never predictable to the patient, producing a bizarre, complicated and erratic type of movement. As the cerebral cortex is not involved in these cases, mental impairment is rarely present and there is an absence of the "stretch reflex." This can be demonstrated by repeated passive flexion and extension movements, at which time the tension usually disappears in the athetoid type but not in the patient with true spasticity. The athetoid group has further been divided into the *tension* and *nontension varieties.*

A spastic condition in general predominates and pain is seldom present. The patient becomes fatigued easily, has weakness of the limbs, particularly the lower limbs, and often presents a disordered gait and station. There is an increase of the deep tendon reflexes and the ophthalmoscope frequently reveals pallor of the optic disks on the temporal side. There may be optic atrophy, transitory diplopia and paresthesias. Disturbances of deep sensation occur more often than disturbances of objective cutaneous sensation. The abdominal reflexes are usually diminished or lost.

In most instances, the Babinski sign is present and intention tremor in the upper limbs is conspicuous as illustrated by lifting a glass of water.

Multiple sclerosis usually runs a chronic course. It begins insidiously and the early symptoms have a tendency toward remissions, but when finally established, they progress over several decades, and incapacity follows. In most instances, an intercurrent disease is the cause of death.

In the acute or subacute clinical forms of multiple sclerosis, symptoms appear quickly and increase rapidly, often causing the death of the patient within a few months or a year.

In occasional instances the disease may occur with only the symptoms of lateral or postlateral sclerosis, or even transverse myelitis. The diagnosis will be dependent on laboratory examinations and serum reactions excluding other forms of spinal cord disease which produce the same symptoms.

In multiple sclerosis the spinal fluid is uniformly clear and colorless and shows normal pressure. The cell count may be slightly increased, but generally is normal. In some instances there is a small increase of protein and half of the cases show a paretic type of gold curve in the gold chloride test. These patients stand lumbar puncture poorly.

Prognosis. The prognosis is always poor, and although the duration of the disease is variable, lasting sometimes for several decades, recovery has not been known to happen. It primarily is a progressive disease and fatal complications develop.

Treatment. Due to its underlying pathologic picture, there can be no specific or permanently effective treatment. Various mechanical appliances such as leg braces are employed when necessary.

Syringomyelia

Syringomyelia is a degeneration in the central nervous system,

avoid disappointment. The operations most suitable in the spastic type are (1) the Stoeffel neurectomies, and here selective procaine nerve block as a preliminary to neurectomy should be done; (2) the lengthening of the shortened tendons (which should not be done in the growth period); (3) transposition of muscles, which should be rarely done and only after bone growth has ceased; and (4) bone stabilization operations, which are at times quite successful in this type.

In the *athetoid* patient, elimination of the seemingly aimless motions can be accomplished by muscle training and voluntary relaxation, and only after this period can voluntary motions be taught. Rarely is surgery indicated.

For the *ataxic* patient, emphasis must be placed on training in balance and co-ordination, for surgery has no place in the treatment of this type of case.

For the *tremor and rigidity* type, treatment by physical and occupational therapy methods are of little value and drug therapy seems to offer the best results. The following drugs have been most satisfactorily used in these types of cases and seem to be of definite value: phenobarbital, belladonna, atropine, Dilantin, curare and, more recently, Myanesin.

The application of plaster of Paris casings for the upper or lower extremities is often very helpful in correcting contractures. Properly fitting braces are useful in some cases and the operations most satisfactory are the hamstring and adductor tenotomies.

Multiple Sclerosis (Disseminated Sclerosis)

This disease occurs most frequently in young adults between 15 and 40, and is a diffuse structural disease of the central nervous system with scattered areas of degeneration. It is one of the most common organic diseases of the nervous system. It occurs more frequently in Europe than in the United States. The cause of the disease is unknown.

The pathologic features of the disease are swelling and disintegration of the myelin sheaths, axon degeneration, and proliferation of neuroglia tissue, causing the formation of scattered areas of sclerosis originating in the brain or spinal cord. Vulpian and Charcot in 1860 recognized this as a disease.

Clinical Picture. Due to the multiplicity of the pathologic degenerative lesions found throughout the central nervous system, a wide variety of symptoms will be present. The classic ones of nystagmus, scanning speech and intention tremor are frequently found but are not constant.

central nervous system affecting the muscles through the nerve channels; (2) that there is a disturbance of the endocrine system; and (3) that it is due to an intrinsic nutritional defect of the muscles. It may be transmitted through either parent but usually through the mother;

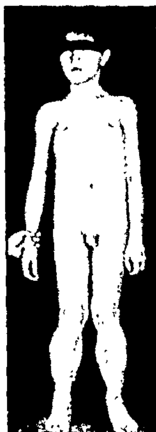


FIGURE 423. Progressive muscular dystrophy. Note the tremendous enlargement of the calves and atrophy of the shoulder girdle muscles.

boys are far more often affected than girls and it appears to be confined to the white race.

Certain clinical varieties can be recognized and those most often seen in orthopaedic practice are described below.

The *pseudohypertrophic type* starts in very young children, with hypertrophy of the calf muscles and atrophy usually confined to the upper half of the body and the proximal parts of the limbs.

In the *juvenile form* or *Erb type*, the muscles of the shoulder girdle and upper arm are first affected, starting in youth or middle life. These muscle groups of the shoulder girdle as well as the muscles of the pelvic girdle show pseudohypertrophy, but the thighs and deep muscles of the back and the upper arms show muscle atrophy. As the disease progresses, however, the hypertrophied muscles undergo marked atrophy.

Hysterical Joints

Functional affections may give rise to severe deformity and marked instability of a joint which are due entirely to psychoneurotic causes. This is seen in those patients in whom there is no actual disease or weakness but rather an element of mental instability. This class of patient is often difficult to cure, and frequently a consideration of any financial compensation for the injury received must be properly evaluated.

Often the joint symptoms are out of all proportion to the inciting trauma, varying in intensity from day to day. A very careful physical examination is always essential, for such a diagnosis as hysteria must not be made lightly. Examination of the joint involved, under an anesthetic if possible, may be of assistance. There is usually an absence of muscular atrophy.

Treatment. Although functional and structural disorders may coexist to confuse the picture, a pure hysterical joint is occasionally seen and its treatment is largely a psychiatric problem. A complete change of environment may help. Rest in bed is rarely indicated. Physical therapy of a corrective type may be permitted as well as occupational therapy, but in some compensation cases, a financial settlement of the suit and closure of the legal aspects of the case will quickly be followed by a disappearance of the disability.

Progressive Muscular Dystrophy (Pseudohyperthcrophic Muscular Dystrophy)

This disease is seen fairly often in orthopaedic practice. It is believed to occur more often than other forms of muscular atrophy in children, and is generally bilateral in distribution. It may be primarily based upon disturbances of the sympathetic muscular innervation. It may affect several children of a family without previous history of a similar condition in the family; however, an element of heredity is present in about three-fifths of the cases. It usually begins in early or middle childhood, though it has been known to begin in adult life. It is generally characterized by a symmetrical progressive hypertrophy of certain muscle groups, especially enlargement of the calves of the legs, and later in the disease by an atrophy of the muscles of the shoulder girdle and back (Fig. 423) This is not a real muscular hypertrophy, but the individual fibers become swollen with a substitution of fat and connective tissue. Its exact cause is unknown, but three theories have been advanced: (1) that it is due to disturbances in the midbrain or

ment has been discovered. Various types of medication have been reported of value in improving the condition, such as taking glycine by mouth (Voshell, 1933), with or without subcutaneous injections of epinephrine and pilocarpine (0.2 to 0.3 cc. of 1/1000 epinephrine and 0.1 to 0.2 cc. of 1 per cent solution of pilocarpine hydrochloride daily or every other day, up to 60 doses) (Kure and Okinaka, 1930), but the improvement has been only temporary. Physical therapy sometimes is of value in improving the general muscular tone. Operation has nothing to offer these cases with the exception of occasionally overcoming contractures by tenotomies, which may make walking easier. An orthopaedic back brace offers some aid in lessening lordosis. It is, however, very important to keep this type of patient ambulatory as long as possible for early bed rest hastens the time when they will become bedridden.

Progressive Muscular Atrophy of the Charcot-Marie-Tooth Type

The Charcot-Marie-Tooth type of progressive muscular atrophy was described independently in 1889 by Charcot and Marie in France and by Tooth in England. It is also known as *progressive neural (neurotic) muscular atrophy.* The disease may be dependent upon prenatal developmental defects of the nervous system, but no exact cause is known. The lesions consist of degeneration of the posterior columns of the spinal cord and atrophy of the anterior horn cells with marked changes in the peripheral motor nerves. It is hereditary and familial in character.

Clinical Picture. This disease begins in childhood, in adolescence or in early adult life before the twentieth year, and occurs in males more frequently than in females. Its onset is insidious and its course slowly progressive, sometimes with remissions of great length. Several individuals of the same family are frequently affected. It can be transmitted from one generation to another but it may skip a generation.

One of the earliest signs is an increasing difficulty in walking, due to weakness of the muscles supplied by the peroneal nerves. The deformity of pes varus or pes equinovarus develops early. At first the atrophy appears to be limited to those muscles below the knee; later, the muscles of the hand and then those of the forearm show a marked atrophy with some disturbance of sensation in the lower limbs below the knee. The shoulder, trunk and facial muscles usually escape involve-

Another clinical type is the *facioscapulohumeral* or *Landouzy-Déjérine atrophy,* which involves the muscles of the face and shoulder girdle primarily. In this type no muscle pseudohypertrophy occurs, but there is marked atrophy of the muscles of the face, shoulder girdle and arms. Due to this muscular atrophy, the lips appear thickened; however, the ocular muscles and the muscles engaged in swallowing are not affected. When the patient's body is lifted up by the examiner placing his hands in the axillae the body seems to slip through his hands, due to the atrophy and weakness of the shoulder muscles.

Clinical Picture. The usual type of pseudohypertrophic muscular dystrophy shows early muscle weakness with awkwardness in walking, which causes the patient to find climbing stairs extremely difficult. A characteristic waddle, increased lordosis and an early enlargement of the calves are seen. The latter gives the appearance of great strength but an examination reveals marked muscular weakness. If the patient is placed in a sitting position on the floor and attempts to gain the erect posture, a characteristic method of arising is noted. It is done awkwardly and with difficulty as follows: Turning over, he rests himself on his hands and knees on the floor and then slowly and progressively pulls himself to the standing position, at the same time sliding the hands along the legs and thighs to brace himself until he gains the erect posture. This characteristic movement of climbing up on his lower extremities is a very early sign and in suspected cases this test should always be tried. The age of onset is usually between 2 and 8 years.

At the onset of the disease, when dystrophy is hardly perceptible, and always when it becomes definite, the tendon reflexes are absent. There are no disturbances of sensation. Involvement of the sphincter muscles never occurs. In rare instances the heart muscle and the diaphragm have been involved.

Thus the conspicuous manifestations of the disease are the atrophy beginning in the proximal parts of the extremities, the lack of fibrillary tremors, the usual bilateral distribution of the disease and the lordosis which develops following the wasting of the back muscles.

Prognosis. The disease is usually slowly progressive, but occasionally the symptoms may remain stationary over many years. The majority of the patients die before reaching middle life through some intercurrent infection, especially of the respiratory system. The earlier the onset, the poorer the prognosis.

Treatment. Up to the present time no satisfactory method of treat-

disease, as in the past confusion occurred between the terms "myotonia congenita" and "myatonia congenita."

This is a rare disease characterized by extreme muscular relaxation and weakness. The infant's muscles are flabby and atonic, presenting severe muscle relaxation, and the deep reflexes are absent. The lower extremities are particularly involved and passive movement demonstrates this extreme muscular relaxation. The disease is congenital. It is thought to be mostly an affection of the lower motor neuron system. Symptoms appear at birth or occur in the first few months of life. Usually a few weeks after birth movements of the lower limbs are absent; the head cannot be raised, and all muscles are flaccid.

Prognosis. Over one-third of the patients die within the first year.

Treatment. The cause is not known and there is no satisfactory treatment.

INJURIES TO PERIPHERAL NERVES

Any of the peripheral nerves may be injured by penetrating wounds or when compressed against bone, caught in scar tissue, stretched or torn during delivery; weakness or paralysis of the muscles supplied by the nerve follows. Only the more common types met with in orthopaedic practice are reviewed.

Erb's Palsy (Obstetric Paralysis; Birth Palsy)

Etiology. Erb's palsy is produced through stretching or tearing of a portion of the fibers of the brachial plexus at birth and occurs by forcibly widening the distance between the head and the shoulder. It is commonly seen in infants born after a prolonged and difficult labor. Certain of these cases may have an underlying congenital lack of development of the glenoid cavity which predisposes them to subluxation. The history of a difficult labor, however, is so routinely obtained that is it probably the primary cause for the development of Erb's palsy.

Clinical Picture. It is characterized by various degrees of disability of the upper extremity, depending upon the location at which the nerves are injured.

There are three varieties of paralysis, the *upper*, the *lower* and the *whole arm types.*

The *upper arm (Erb-Duchenne) type* is the one most frequently seen, occurring about four times as frequently as the other two types. It is caused by an injury to the fifth and sixth cervical trunks (Erb's

ment. Finally the wasting may be present in the more proximal muscles of all the limbs. The tendon reflexes are generally absent. Paresthesia and pain in the extremities may at times be among the complaints.

Prognosis. Though the disease is slowly progressive, the patient may live for many years and die from intercurrent infection.

Treatment. There is no specific treatment. Deformities of the feet may be treated by braces or by stabilizing operations. Occasionally lengthening of the heel cords will permit the patient to balance himself better in walking.

Myotonia Congenita (Thomsen's Disease)

This chronic progressive condition begins in early life but may not be detected until 12 or 14 years of age. It usually affects several members of the same family, being transmitted from generation to generation. It may occur sporadically.

Clinical Picture. It is characterized by muscle stiffness or hypertonicity which is present particularly at the beginning of voluntary movements and lessens as motion is continued. Fatigue, excitement and subjection to cold make the difficulty more pronounced. Individuals with oversized muscles are usually the ones affected.

In the late stages of the disease all voluntary action is more awkward and difficult, especially the rigidity in the legs, making it difficult for the patient to walk normally. Some decrease in muscular power is noticed.

Usually the muscles of the lower limbs are affected, but those of the upper extremities, face, the elevators of the eyelids and the masseters many also be involved. The degree of the affection is different in various muscles. Sensation is not involved. The tendon reflexes may at times be absent, diminished, increased or normal. "Myotonic reaction" is shown in the electric examination.

Prognosis. The disease progresses to early adult life, then seems to remain practically stationary. At times there are relapses and remissions.

Treatment. Quinine hydrochloride, 5 to 10 grains two to three times daily, is said to be of value in combating the hypertonicity. The patient should not be exposed to emotional upsets.

Myatonia Congenita (Oppenheim's Disease; Amyotonia Congenita)

The term "amyotonia congenita" is generally used to describe this

acute trauma produced by traction of the arm during delivery. The arm hangs limp at the side.

Complications. The whole arm type presents the poorest prognosis. In all types the humerus may be dislocated or the clavicle fractured at the time of the injury to the plexus.

In the upper arm type, the patient not only develops contractures of the soft parts, but also, because of the long-continued fixed internal rotation, the head of the humerus in the older cases may be found subluxated backward and the arm abducted and flexed on the scapula. In these late neglected cases a severe restriction to motion occurs, and many times a marked curving downward or elongation of the acromion process gives rise to mechanical limitation from bony block of the deformed acromion process.

Prognosis. In many young infants following the birth injury, only edema is produced about the brachial plexus, although the characteristic deformity of the upper or lower arm type follows. In these patients simple support in the proper attitude of abduction and external



FIGURE 425. *Obstetric paralysis of the left arm. The left arm is pinned* to the mattress in the attitude of abduction and external rotation with the elbow flexed ("traffic cop" position). There is a restraining band across the chest.

point), involving the deltoid, supraspinatus and infraspinatus, the biceps, coracobrachialis and supinator muscles of the forearm. The extremity hangs at the side in the characteristic attitude (Fig. 424), the arm is rotated inward, the forearm pronated, and the elbow and wrist flexed in the so-called "waiter's tip" attitude. The movements of the wrist and fingers are not affected in the upper arm type.



FIGURE 424. Obstetric paralysis in infancy. Note the characteristic attitude of inward rotation and pronation of the right arm. (From Whitman, *Orthopaedic Surgery*, Lea & Febiger.)

The *lower arm (Klumpke) type*, involving the eighth cervical and the first dorsal nerve, is characterized by paralysis of the intrinsic muscles of the hand, flexors of the wrist and the long flexors of the digits (the claw hand) and by drooping of the upper eyelids, narrowing of the palpebral fissure and contracture of the pupils, because the sympathetic fibers are included in the first dorsal root.

In the *whole arm type*, the extremity is absolutely flaccid and the patient presents a complete paralysis, with complete anesthesia of the hand, forearm and lower part of the arm.

In the first few weeks after birth in all three types the upper extremity is very sensitive to attempted movement and may be swollen from the

cop" attitude (external rotation and abduction with the elbow flexed at a right angle and with the forearm supinated and the hand in slight hyperextension). As the child becomes older, a type of wire splint (Fig. 426) can be bent easily and padded so that the arm can be kept in this position, but once each day it should be taken out for general exercising and massaging. Recovery may be complete by this simple treatment. However, usually a little permanent restriction of motion at the shoulder and some disturbance of growth development in the length of the humerus and size of the scapula will be noted later. Every effort must be made early to restore the head of the humerus to its normal position, and one may check with roentgenograms to confirm this.

The results from repairing the ruptured nerves have not been successful and are not considered to offer any practical benefit.

In the older patient. The foregoing is the treatment in infancy which is instituted before the upper extremity has assumed many accommodative changes and soft tissue contractures.

However, in early childhood and frequently in late childhood, open operation is advisable. The Sever operation is often used. This is a division of the contracted pectoralis major, the subscapularis and its underlying contracted joint capsule so that outward rotation may be obtained. The arm is stretched into abduction and external rotation and a plaster spica applied (Fig. 427).

In certain cases, complete correction by either closed manipulation or open operation cannot be obtained in one sitting and it may be necessary to remanipulate the joint, gradually placing it in a more extreme degree of overcorrection in plaster. These plaster spicas remain in place 6 to 8 weeks; after removal a long and intensive course of physical therapy follows.

It is not always sufficient simply to divide the contracted tissues. A muscle transplantation after the method of L'Episcopo (1934), who transposed the teres major into the posterior and lateral aspects of the humeral shaft, thus making this muscle an active corrective force, may be desirable.

Occasionally in older children a high osteotomy on the humeral shaft may be done to overcome the longitudinal torsion of the humerus.

The anterior portion of the shoulder capsule in the *untreated case* becomes contracted and thickened, and the reverse accommodative change is true posteriorly, there being a tendency to subluxation of the humeral head in the older untreated case. The acromion process

rotation permits a partial or complete return of function. Certainly if the case is examined shortly after birth and proper support applied, 3 to 6 months should elapse before concluding that there will not be a return of function.

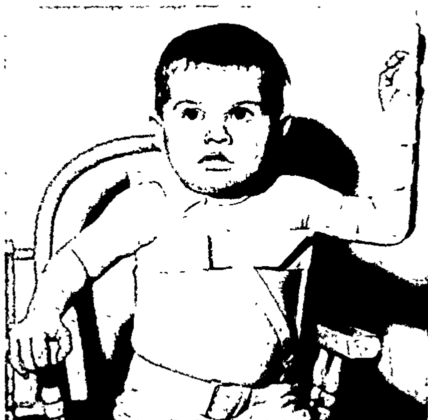


FIGURE 426. Child with obstetric paralysis Light wire splint holds the arm in "traffic cop" position. Note the strap over the opposite shoulder, which holds the splint snugly in position.

In the lower arm type, when there is paralysis of the intrinsic muscles of the hand, a claw deformity may arise and then the prognosis is not favorable.

In the whole arm type of palsy, the prognosis is poor and if contraction of the pupil of the eye is present, it indicates the nerve roots have been torn from the cord and permanent disability may be expected.

Treatment. *In infancy.* In the early acute stage with sensitiveness, swelling and acute tenderness, the arm and body of the infant should be attached by bandages to a firm pillow, holding the upper extremity in outward rotation and abduction with the elbow flexed and the forearm and hand supinated (Fig. 425). The arm should be daily moved gently from this position and massaged with olive oil or petrolatum and then replaced in the same position, the so-called "traffic

arm by utilizing the scapulothoracic muscles in movement of the arm.

(4) In the lower arm type, muscle transplantation of the overactive flexor group of wrist muscles to the extensors of the fingers is helpful in the older patients. Even an arthrodesis of the wrist is an effective method of correcting a severely flexed wrist joint as a preliminary to muscle transplantation.

After any operative measure the arm must be adequately supported in the proper position and persistent and skilled physical therapy administered.

Radial (Musculospiral) Nerve

The radial nerve (Fig. 428) has both sensory and motor fibers and is a continuation of the posterior cord of the brachial plexus, having fibers from the sixth, seventh and eighth cervical nerves, and often from the fifth cervical and first thoracic nerves. It passes downward behind and on the lateral surface of the shaft of the humerus in the musculospiral groove where it is frequently the site of injury. It supplies the following muscles: triceps, anconeus, supinator longus, extensor carpi radialis, longus and brevis, supinator brevis, extensor communis digitorum, extensor minimi digiti, extensor carpi ulnaris, the three extensors of the thumb and the extensor indicis. Sensation is supplied on the dorsum of the hand from the wrist to the interphalangeal joint of the thumb and the metacarpophalangeal joints of the index and middle fingers.

Etiology. If a fracture of the humerus occurs along the course of the musculospiral nerve the muscles supplied by it may temporarily or permanently be paralyzed, giving rise to the characteristic feature of *wrist drop* (Fig. 429). If the nerve is pressed upon by some external force sufficiently long to cause injury, for example, by the use of a tourniquet or by resting the arm over the sharp edge of the operating table, a temporary musculospiral nerve palsy may follow.

Clinical Picture. If there is severe trauma or complete division of the musculospiral nerve in the arm before reaching its terminal branches, it will cause a paralysis of the extensors of the elbow, wrist, knuckles and all joints of the thumb, as well as of the supinator and brachioradialis This will give rise to a typical wrist drop as well as to disturbance of sensation of the front and back of the hand in the region of the base of the thumb (Fig. 430).

Treatment. If contusion to the musculospiral nerve is all that is suspected, application of a snug fitting cockup plaster or aluminum

becomes hooked and the internal rotators about the shoulder become contracted, while the paralyzed external rotators are chronically stretched.



FIGURE 427. Postoperative position of the arm in plaster.

Summary. (1) In infancy a large proportion of the cases recover by placing the arm in external rotation and abduction for 3 to 6 months.

(2) If these patients are older, treatment may be first manipulation of the shoulder under an anesthetic, stretching the contractures until they are overcome. A Sever operation, however, is usually more effective. Following one or the other of these procedures, the whole upper extremity is placed in a long plaster spica extending from the fingers to the waist with the forearm supinated, the elbow extended and the shoulder widely abducted, externally rotated and completely extended (see Fig. 427).

(3) In cases of the severe upper arm type which have received inadequate treatment and where restoration of function at the shoulder by manipulation, tenotomy or osteotomy cannot be obtained, an arthrodesis of the shoulder may have to be done. This fusion of the joint permanently reduces the subluxation and improves the function of the

splint will be sufficient. In those cases in which division of the nerve is known, open operation and suture of the nerve ends is advisable. Recovery from nerve suture is slow and usually requires months, but recovery from contusion usually requires only 10 to 12 weeks. The use of electrical stimulation is of value in making the differentiation.

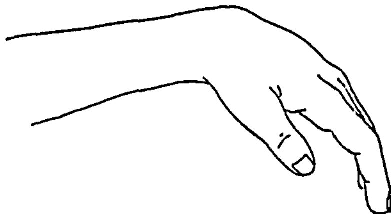


FIGURE 429. Typical deformity of radial nerve paralysis. (From Groff and Houtz, *Manual of Diagnosis and Management of Peripheral Nerve Injuries*, J. B. Lippincott Co.)

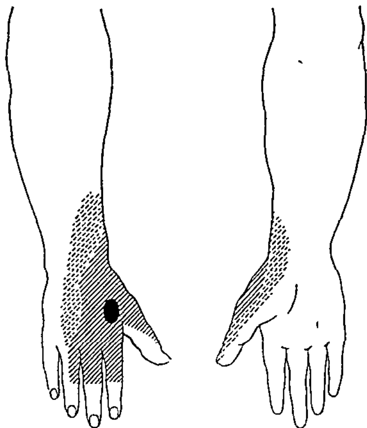


FIGURE 430. Sensory distribution of radial nerve. Shading shows anesthetic areas — complete (black) and partial (shaded) — following paralysis. (From Groff and Houtz, *Manual of Diagnosis and Management of Peripheral Nerve Injuries*, J. B. Lippincott Co.)

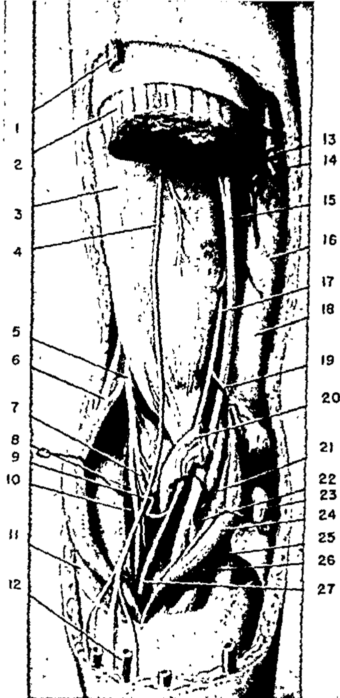


FIGURE 428. The right elbow region viewed from the front with the forearm in supination Portions of the peripheral veins, biceps m., lacertus *fibrosus and fascia have been removed. The brachioradialis m. and the* pronator teres m. have been widely retracted. The deep venous system which closely accompanies the arteries has been omitted for clarity. (From Groff and Houtz, *Manual of Diagnosis and Management of Peripheral Nerve Injuries*, J B. Lippincott Co

1. Cephalic v. *2.* Biceps m *3.* Brachialis m *4.* Cutaneous antibrachii lateralis n. *5.* Radial n *6.* Brachioradialis m *7.* Deep branch of radial n. *8.* Superficial branch of radial n *9.* Recurrent radial a. *10.* Supinator m. *11.* Extensor carpi radialis longus m *12* Cephalic v. *13.* Basilic v. *14.* Cutaneus antibrachii medialis n. *15.* Median n. *16.* Medial intermuscular septum. *17. Brachial a. 18. Ulnar n (posterior to medial intermuscular septum), 19.* Inferior collateral ulnar a. *20.* Biceps tendon and lacertus fibrosus. *21.* Posterior recurrent ulnar a. *22.* Ulnar a *23.* Lacertus fibrosus. *24.* Pronator teres m. *25.* Palmaris longus m *26.* Flexor carpi radialis m. *27.* Radial a.

Clinical Picture. Lesions of the median nerve in the upper arm are always serious. They may result from penetrating wounds, such as stabbing or gunshot wounds, or through lacerating wounds, such as in certain supracondylar fractures of the humerus.

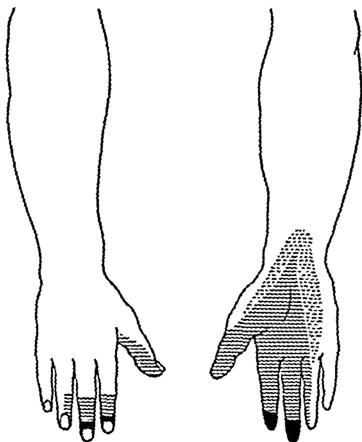


FIGURE 431. Sensory distribution of median nerve. Shading shows anesthetic areas — complete (black) and partial (shaded) — following paralysis. (From Groff and Houtz, *Manual of Diagnosis and Management of Peripheral Nerve Injuries*, J. B. Lippincott Co.)

If there is *complete division* of the *media nerve* in the *arm*, the disability is extensive, based on the above anatomy. Flattening of the thenar eminence in injuries is an easily recognizable sign, as well as inability to flex the terminal phalanx of the thumb against resistance. Sensation is also lost in the three and one-half finger area (see Fig. 431).

If sweating is observed on the palmar surface of the distal phalanx of the index and little fingers it is impossible for a complete lesion of the median or ulnar nerves to be present (Kahn, 1951). If sweating is absent over these areas it is presumptive evidence of a lesion of these nerves and especially so when sweating is present in the corresponding area of the opposite hand.

A very satisfactory method of treating a permanent wrist drop is by an operative transposition of the flexors of the wrist into the extensor group of the fingers.

In any of these instances the wrist must be supported in the cockup position for a time and a long course of muscle training stressed.

Median Nerve

The median nerve is mixed, being derived from the internal and external cord of the brachial plexus. It receives fibers from the sixth, seventh and eighth cervical and from the first thoracic nerves, and sometimes from the fifth cervical nerve. It descends in the arm, giving no branches either in the axilla or in the arm, and exactly bisects the triangular space in the elbow, passing there between the two heads of the pronator teres muscle. It gives off a few small branches to the elbow joint, and, just below the bend of the elbow, it gives off a large branch called the volar interosseous nerve which goes to the deep muscles on the volar aspect of the forearm. The volar interosseous nerve runs down on the interosseous membrane to supply the pronator quadratus and communicates with a branch of the radial nerve on the dorsal surface. It supplies the flexor pollicis longus and the outer half of the flexor profundus digitorum. The median nerve at the elbow where the volar interosseous comes off continues its course down the middle of the forearm so that the median nerve supplies six and one-half of the eight muscles on the flexor surface of the forearm. These are the pronator teres, flexor carpi radialis, palmaris longus, flexor sublimis digitorum, flexor longus pollicis, pronator quadratus and the outer half of the flexor profundus digitorum. Cutaneous branches are given off just before reaching the anterior annular ligament and their distribution is somewhat variable. Usually pinprick sensibilty (Fig. 431) is confined to the terminal phalanges of the thumb, index and middle fingers, slightly more extensive on the palmar than on the dorsal aspect. As the volar branches continue in the hand, they supply all the muscles that arise from the greater multangular (trapezium) and annular ligament, i e , the abductor and opponens pollicis muscles.

In general, it may be said that the median nerve is responsible for the powerful coarse movements of the hand which are produced by the extrinsic muscles, and the ulnar nerve is responsible for delicate movements mainly employing the intrinsic muscles of the hand.

In cases of damage to the median nerve trophic changes may occur in the terminal phalanges of the index and middle fingers

Clinical Picture. Lesions of the median nerve in the upper arm are always serious. They may result from penetrating wounds, such as stabbing or gunshot wounds, or through lacerating wounds, such as in certain supracondylar fractures of the humerus.

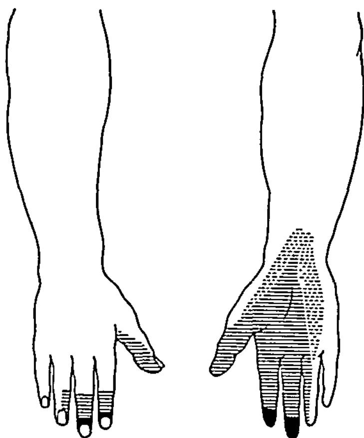


FIGURE 431. Sensory distribution of median nerve. Shading shows anesthetic areas — complete (black) and partial (shaded) — following paralysis. (From Groff and Houtz, *Manual of Diagnosis and Management of Peripheral Nerve Injuries*, J. B. Lippincott Co.)

If there is *complete division* of the *media nerve* in the *arm*, the disability is extensive, based on the above anatomy. Flattening of the thenar eminence in injuries is an easily recognizable sign, as well as inability to flex the terminal phalanx of the thumb against resistance. Sensation is also lost in the three and one-half finger area (see Fig. 431).

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When the division of the median nerve is incomplete causalgia often results.

Injury of the *median nerve* at the *elbow* from supracondylar fracture or from a penetrating wound may result in the nerve being either contused or divided. The jagged edges in certain supracondylar fractures are especially dangerous.



FIGURE 432. Median nerve paralysis. Typical deformity of flexed fingers. (From Groff and Houtz, *Manual of Diagnosis and Management of Peripheral Nerve Injuries*, J. B. Lippincott Co.)

At the *wrist*, following traumatic lesions such as anterior dislocation of the semilunar bone, a median paralysis (Fig. 432) occasionally occurs.

The inability to oppose the thumb is an important sign in lesions of the nerve at the wrist.

Treatment. Exploration is demanded when the lesion is seen early. Where the wound is clean, primary nerve suture should be done wherever feasible; otherwise, secondary suture is done. If the median nerve is caught between the fracture surfaces, it should be freed and the bed lined by fascia lata flaps. Secondary suture of the median nerve is always less satisfactory because the return of sensation is inconstant.

If the primary nerve suture operation is not done with the finest technic, causalgia develops subsequently.

With extensive median nerve damage, considerable length may be obtained by re-routing the nerve more superficially and suturing it with

the elbow and wrist held in marked flexion. After the wound has healed the wrist and elbow are slowly extended, thereby gradually stretching the sutured nerve.

There are various muscle transplantations which can be used in both the forearm and hand when the nerve does not lend itself to suture, and these are described in various books on nerve surgery. The results as regards restoration of function following tendon transplantation for median nerve paralysis leave much to be desired.

Ulnar Nerve

This is a mixed nerve and is the largest branch of the internal cord of the brachial plexus, containing fibers from the eighth cervical and

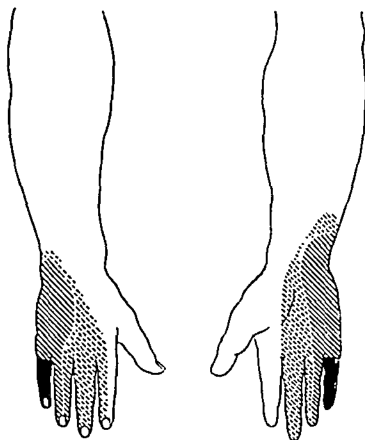


FIGURE 433. Sensory distribution of the ulnar nerve. Shading shows anesthetic areas — complete (black) and partial (shaded) — following paralysis. From Groff and Houtz, *Manual of Diagnosis and Management of Peripheral Nerve Injuries*, J. B. Lippincott Co.)

first dorsal nerves. It lies along the medial aspect of the arm, passing downward between the internal condyle of the humerus and the olecranon process of the ulnar without giving off any branches until it is

past the elbow joint; then it supplies muscular branches to the flexor carpi ulnaris and the inner half of the flexor profundis digitorum, and about the wrist and hand it has the sensory distribution shown in Figure 433. The ulnar nerve has an extensive motor supply to the muscles of the hand. It supplies all the intrinsic muscles of the hand with the exception of the abductor pollicis brevis, the opponens, the lateral head of the flexor pollicis, and the two lateral lumbricales.

Etiology. The ulnar nerve may be injured by lacerations and gunshot wounds, but probably the most frequent involvement occurs from fractures about the inner aspect of the elbow. If the nerve is not injured at the time of an accident to the elbow, it may be caught in the



FIGURE 434. Ulnar nerve injury. Note characteristic attitude of hand and atrophy of dorsal interossei muscles.

subsequent scar tissue developing about this region. In the laboring man the loss may be only an inconvenience, but in the musician or watchmaker injury to this nerve may be a tragedy.

In cases of "late ulnar paralysis" following fracture about the elbow, the nerve symptoms may develop slowly, even years after the original trauma. A cubitus valgus deformity of the elbow may cause the nerve

to be put under increasing stretch and give rise to the characteristic late ulnar nerve pressure signs (*delayed traumatic neuritis*). As the ulnar nerve controls the finer movements of the fingers, lack of precision in the finer hand movements is noticed along with the loss of abduction and adduction of the fingers, and the characteristic semi-flexed attitude of the ring and little fingers (Fig. 434).

Clinical Picture. This is a very striking one. The normal muscle prominence of the first dorsal interosseus is lost and the other interossei between the metacarpal bones show their muscle atrophy early. The ring finger and the little finger are flexed and the latter falls away from the hand with flattening of the hypothenar eminence. At the wrist, active contraction of the flexor carpi ulnaris cannot be obtained.



FIGURE 435. Claw hand resulting from median and ulnar nerve injury.

The pain at the moment of injury is usually severe, and the patient complains of shooting or stabbing pains extending down into the middle and ring fingers. Later this injury gives rise to the *claw hand* or "main en griffe" (Fig. 435). A simple way to test weakness of the interossei and lumbricales is to have the patient grip a thin piece of paper between the extended fingers. If the lesion is at or above the elbow, the patient cannot flex the terminal phalanx of the little or ring fingers

or perform ulnar flexion at the wrist. Weakness of these muscles is noted soon after injury.

Sometimes the nerve is *injured* at the *wrist*, often in combination with a division of the flexor carpi ulnaris tendon so that the nerve injury is initially overlooked. The exact clinical picture will be materially affected, depending upon whether the location of the lesion is proximal or distal to the two muscular branches at the elbow and the dorsal cutaneous nerve which branches off about the middle third of the forearm.

Treatment. Following clean lacerated wounds, primary nerve suture is advisable, consisting of an end-to-end suture. The other muscles of the hand may appear to take over the hand function shortly after nerve suture, but a return of motor or sensory function following ulnar nerve suture is rare within less than 6 months. The recovery of function in the small muscles of the hand following nerve suture is much slower than that of the extrinsic muscles. Usually motor recovery precedes recovery of sensation.

The ulnar nerve is frequently pressed upon at the point where the nerve curves behind the internal epicondyle of the humerus. Here treatment consists of removal of the ulnar nerve from its groove and re-routing it on the flexor surface of the elbow. Occasionally complete section or fraying of the nerve fibers requires excision of a portion of the nerve. After transferring the nerve to the anterior region of the elbow and resuturing it, both the wrist and elbow are acutely flexed and held in a splint. This permits approximation of widely separated nerve ends, even though the resection may be up to 2 inches in length. This acute flexion position is maintained for several weeks and then the joints are gradually extended. This transposition is particularly valuable in cases in which the symptoms may arise from compression or impingement due to scar tissue or callus following previous bone injury to the medial epicondylar region.

Axillary Nerve

This mixed nerve arises from the posterior cord of the brachial plexus, containing fibers from the fifth and sixth cervical nerves, and passes through the quadrilateral space to the posterior surface of the humerus, and then divides into an anterior and posterior branch, or superior and inferior portions The anterior (superior) division is usually the one injured. This accompanies the posterior circumflex artery of the humerus and ends near the anterior border of the deltoid, being distributed

to this muscle. The posterior (inferior) branch has a cutaneous branch which supplies the skin over the lower third of the deltoid and a muscular branch distributed to the teres minor and deltoid muscles.

Etiology. As the circumflex or axillary nerve winds around the neck of the humerus, it may be injured during fracture of the surgical neck of the humerus, in subcoracoid dislocation or from crutch pressure, the latter giving rise to the so-called "crutch paralysis."

Clinical Picture. When the axillary nerve is injured it produces a paralysis of the deltoid muscle with loss of true abduction at the shoulder and pronounced atrophy of this muscle. A flattening of the shoulder and a prominence of the acromial end of the clavicle can be observed. When the posterior branch is injured there is some sensory loss over the deltoid prominence, with function of both the deltoid and teres minor muscles affected.

Treatment. Because of its location, operative surgery is not indicated. In simple contusions to the axillary nerve, nonoperative treatment consists of supporting the arm on an airplane splint (see Fig. 496). In crutch paralysis, simple discontinuance of the traumatizing force produced by the crutch may be all that is necessary for recovery. In severe and permanent damage to the deltoid muscle a shoulder arthrodesis often becomes necessary, or a muscle transplantation operation to obtain abduction of the arm, substituting a part of the trapezius muscle for the paralyzed deltoid, may be considered.

Long Thoracic Nerve of Bell (Posterior Thoracic Nerve)

The long thoracic nerve of Bell or posterior thoracic nerve arises at the root of the neck from the brachial plexus and takes origin from the fifth, sixth and seventh cervical nerves, supplying the serratus magnus muscle.

Etiology. The principal orthopaedic interest in this nerve lies in the fact that it supplies the muscle lining the ventral surface of the scapula, part of whose function it is to hold this bone against the chest wall, and, in part, to abduct the arm above the horizontal plane. If, therefore, this nerve is injured, the patient cannot raise the arm above the level of the shoulder anteriorly without producing a winging of the scapula (see Fig. 417). This "winged scapula" often is also noted in certain cases of infantile paralysis when the anterior horn cells supplying this nerve are affected.

Isolated paralysis from trauma is not common. However, direct injury to the nerve may be caused by perforating wounds in the supra-

clavicular fossa or the axilla, by blows on the neck, by severe stretching on extending the arm above the head, or by holding heavy weights on the shoulders.

The *symptoms* are rarely striking but the deformity produced is quite marked. The *prognosis* is unfavorable in the cases where severe injury is the cause.

Treatment. If contusion to the nerve occurs, physical therapy and simple rest to the shoulder in an abduction splint with a pressure pad against the winged scapula may be sufficient to permit recovery, but in poliomyelitis cases operative methods may be necessary. This consists of fastening the lower angle of the scapula to the chest wall by fascial strips.

Sciatic Nerve

This mixed nerve is the largest in the body. It leaves the pelvis through the great sacrosciatic foramen. The lumbosacral cord is a product of the fifth lumbar nerve and a branch from the fourth. The region where the first, second, third and one-half of the fourth sacral nerves unite with the lumbosacral cord is called the sacral plexus. The sciatic nerve is a composite nerve which includes the external popliteal nerve, the internal popliteal nerve and the nerves of the hamstrings, all within one sheath. The branches to the hamstring muscles leave the trunk early; thus, these muscles are rarely involved in injuries to the sacral plexus. The sciatic nerve can be felt at a point midway between the ischial tuberosity and the lesser trochanter, and its two femoral branches divide at varying levels in the thigh. It passes down the thigh under cover of the gluteus maximus, being comparatively superficial at its lower border. Here it may be injured by contusion or laceration most easily. It descends and divides into its terminal branches, external popliteal (common peroneal) and the internal popliteal (tibial) nerves; this division usually occurs a few inches above the popliteal space

The external popliteal (common peroneal) nerve is more frequently affected than the main trunk or the internal popliteal (tibial) nerve. It arises from the fourth and fifth lumbar and the first and second sacral nerves, dividing low in the thigh and running laterally through the popliteal space, passing subcutaneously below and behind the head of the fibula. Here it penetrates the peroneus longus muscle and then divides into its terminal branches — the superficial peroneal nerve (musculocutaneous) and the deep peroneal (anterior tibial) nerve.

Etiology. Paralysis of the sciatic nerve is infrequent. It may be involved in gunshot wounds, in traumatic posterior dislocation of the hip, or injured during the closed reduction of a congenital dislocation of the hip. Too vigorous manipulation of the hip joint may contuse the sciatic nerve, causing a temporary paralysis.

The superficial portion of the external popliteal nerve around the head of the fibula is most susceptible to injury by direct trauma or from expanding tumors of the head of the fibula. Occasionally the nerve is injured during operative procedures about this region.

Clinical Picture. With a complete sciatic paralysis, there is anesthesia on the posterior surface of the extremity, the outer surface of the leg, and the dorsum and sole of the foot, and all the muscles below the knee are paralyzed. There is an awkward steppage gait in order for the drop foot to clear the ground, which makes walking difficult. The ankle jerk is absent and trophic ulcers tend to occur at the tip of the heel and the outer border of the foot.

In external popliteal (common peroneal) nerve injuries resulting in complete paralysis there is loss of dorsiflexion with inversion of the foot, flexion of the toes and disturbance of sensation over the dorsum of the foot and the outer part of the leg.

In internal popliteal (tibial) nerve injuries resulting in complete paralysis the foot is held dorsiflexed at the ankle and everted (calcaneovalgus). Prominence of the Achilles tendon is lost, and the "push" of the foot is lost when walking.

Treatment. Simple contusion with temporary paralysis is best treated by a spring type of foot brace for walking and a night splint to hold the foot in the overcorrected position. Nerve suture on the internal or external popliteal nerves may be done when the injury is fresh, and is a clean-cut transverse division. However, foot deformities frequently develop after these nerve injuries for they rarely obtain early adquate treatment. In the late stage it is best treated by having the foot deformity corrected with one of several orthopaedic operative procedures, such as a muscle transplantation or a bone stabilization operation or both.

When the sciatic nerve has been completely divided, operative exploration and sciatic nerve suture may be considered, but the results are not encouraging. During these operations, and postoperatively, care must be taken to see that the lower extremities are supported in the best position to avoid tension on the sutured nerve. When severe trophic ulcers develop about the foot and leg, amputation may have to be done.

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16

Tumors of the Bone

Tumors of bone comprise a small but very important portion of the practice of an orthopaedic surgeon. They may be benign growths, a malignant tumor arising primarily from osseous structures, or a metastatic tumor involving the skeletal system which may simulate a true bone tumor. What is a tumor of bone? Coley (1949) defines a tumor of bone as a new growth arising in a bone or derived from cells which are components of skeletal tissue. He points out that by common usage this includes not only tumors arising in cartilage but also those derived from cells in the marrow and from the specialized connective tissue covering the bone, namely, the periosteum. It is not the prerogative of this book to go into minute detail on all the various subdivisions of bone tumors as many of the subgroups are controversial and many authors disagree as to whether or not these subgroups exist or whether or not a different classification might not be better for some of them. Although the study of bone tumors has gone on for a long period of time, it was not until 1922, when Codman pioneered the establishment of the Bone Sarcoma Registry of the American College of Surgeons, that order started to come from chaos. Since that time rapid strides have been made. However, there is still no unanimity of opinion as to classification, diagnosis, or a completely standard method of treatment in each instance.

Probably the simplest classification of bone tumors is that adapted by the Bone Sarcoma Registry of the American College of Surgeons and revised by Ewing in 1939. Coley (1949) has slightly modified

TABLE 3

CLASSIFICATION OF BONE TUMORS *

Malignant	*Benign*
Fibrosarcoma of bone	Nonosteogenic fibroma of bone
Osteogenic sarcoma	Osteoma
	Osteoid osteoma
	Exostosis
Primary chondrosarcoma	Chondroma
Secondary chondromyxosarcoma	
Malignant giant cell tumor	Benign giant cell tumor
	Benign chondroblastoma (Codman's epiphyseal chondromatous giant cell tumor)
	Unicameral bone cyst
Endothelioma (Ewing's sarcoma)	Cavernous angioma
Angiosarcoma	Plexiform angioma
Myeloma { plasma cell myeloma myelocytoma erythroblastoma lymphocytoma	
Reticulum cell sarcoma	
Liposarcoma	

* Coley, B. L. *Neoplasms of Bone and Related Conditions.* New York, Paul B. Hoeber, Inc., 1949.

this and has brought it up to date (Table 3). There are other classifications, namely, those propounded by Geschickter and Copeland (1949), Lichtenstein and Jaffe (1940) and Jaffe (1958). We would suggest for a more detailed treatise on bone tumors that these references be consulted.

For the sake of completeness the primary tumors in bone, the metastatic tumors involving bone and those lesions which simulate bone tumors are discussed in this chapter.

EXAMINATION

As is true of the care of all patients with any disease, a complete history and physical examination is essential. It is necessary to note the patient's age, sex, and duration of symptoms. *Benign tumors* are generally characterized by slow growth with a gradual onset of symptoms and very little, if any, systemic reaction. *Malignant tumors* vary in rates of growth but generally grow faster than benign tumors. As they do metastasize, they may give a picture of generalized cachexia,

loss of weight, and other generalized systemic phenomena. *Metastatic tumors to bone* may arise from prostrate, breast, kidney, thyroid, and lung in approximately this order of frequency. It is important, therefore, to go into the past history regarding any operations that have been done, what they were for, and to obtain, if possible, the actual pathologic diagnosis of the tissue removed at operation.

Clinical Picture. One of the symptoms which we very often see with primary bone tumors or metastatic tumors from other lesions is the history of severe night pain, with a rheumatic type of pain during the daytime. When this occurs, malignancy in bone should be suspected until proven otherwise. If the lesion is in the extremities, ordinarily the patient's pain occurs at the site of the lesion. However, in those lesions affecting the vertebral column it is common to have a history of a radicular type of pain, the symptoms being peripheral to the lesion. The author has seen one patient, age 59, who came in with what appeared to be a typical history and physical findings of a ruptured intervertebral disc. This man even had positive findings by myelogram. However, the final diagnosis was hypernephroma, metastatic to the fourth lumbar vertebral body with soft tissue encroachment on the spinal nerves in this area, giving the symptom complex.

Another patient, age 35, came in with the complaint of stiffness of his neck with pain down the right upper extremity. His only physical findings were an absence of the triceps reflex and some limitation of motion in the cervical spine. Further investigation showed that he had a lesion in the cervical spine secondary to a hypernephroma.

As far as trauma is concerned, certainly a single trauma cannot produce a primary tumor of bone. However, one very often gets a history of antecedent trauma in both benign and malignant tumors. Many of the lesions in these tumors are in the lower end of the femur or the upper end of the tibia. Falling is a common occurrence for patients with such lesions, especially in the younger age groups. It is common to find a mother who, following a fall by her child, notices a bony prominence which she thinks is abnormal. This may be the reason the child is brought to the physician, the tumor having been their prior to the fall which gave rise to examination of this part. In cystic-type tumors, such as giant-cell tumors or solitary bone cysts, very often some very minor trauma causes a pathologic fracture and thus also brings the lesion to light.

The so-called Ewing's tumor may actually simulate an infection and give rise to increased temperature, leukocytosis, and warmth

over the involved area. The differential diagnosis here might be between osteomyelitis and Ewing's tumor, but certainly a past history of tonsillitis, tooth infection or trauma should not be ignored.

Physical findings by local examination, inspection and palpation and local deformity may be evident in a tumor which has been present for a fairly long period of time or in a tumor which is rapidly growing. Persistent symptoms should never be ignored. Some of the tumors, such as osteoid osteoma, show few physical characteristics. The history should not be ignored even with negative physical findings and an exhaustive study by roentgenograms and biopsy may be necessary.

In the slow growing benign tumors, such as the osteochondroma, there may be no physical findings until the tumor becomes large enough to impinge on vital structures, giving rise to symptoms by its size. In the more rapidly growing malignant tumors, particularly the osteogenic sarcoma, one notes a dilatation of the superficial veins, a thinning and shiny appearance of the skin and an increase in local temperature over the tumor area. Some of the cystic lesions, notably the giant-cell tumor and the solitary cyst of bone, may give rise to the so-called "egg-shell-cracking" feeling to the examiner as he puts his hand over the tumor area, if pathologic fracture has occurred. In both the aforementioned lesions, the fracture may occur after very minimal trauma and in examining the part there is not the tremendous amount of pain that one would get in an ordinary traumatic fracture. This absence of severe pain should make one think of a pathologic fracture, either from a bone cyst or from a giant-cell tumor, or from any of the metastatic tumors which may occur in long bones.

Roentgenographic Examination. The history, physical findings and roentgenographic examination should give us a lead as to which pathologic process we are dealing Roentgenograms are essential. It is, therefore, imperative that every effort be taken to get adequate views and to obtain films which are as nearly perfect technically as possible. This is especially true in lesions in the area of the upper humerus, where very often the roentgenograms are not adequate and the patient is treated with diathermy or some modicum of physical therapy, only to find out later on one is dealing with a malignant bone tumor. If the signs and symptoms point to a tumor and the roentgenographic findings are negative, it is essential they be repeated at three-week intervals until an accurate diagnosis can be made. It may be necessary to take many oblique views or body section views before the lesion may be shown roentgenographically. It may also be necessary to take com-

parable views of the contralateral side and compare them, as many lesions may be delineated in this manner.

In any bone tumor one should not be satisfied with films of the lesion itself. A chest plate and a bone survey should always be included. Attention may be focused to a single lesion which appears to be a solitary bone cyst only to find on bone survey that this is a polyostotic form. Many lesions look relatively innocuous. However, it may be a malignant lesion which has metastasized to the chest. It is, therefore, imperative that any person suspected of having a bone tumor have a routine chest plate taken as part of the original examination.

The histologic picture (see Biopsy, p. 699) of the tumor itself is important.

Laboratory Studies. There may be significant changes in the blood and urine of patients with bone tumors. These may be changes in the acid or alkaline phosphatase, in the total protein, or in the albumin-globulin (A/G) ratio; also, the calcium and inorganic phosphorous levels may be affected. Table 4 and Table 5 show some of these changes.

Alkaline phosphatase may be found elevated in lesions other than those of osseous origin. It is found elevated in the active phase of bone growth, which includes that period before the epiphyses are normally closed, or in fractures in growing children. However, it is also increased in cases of osteogenic sarcoma, Paget's disease, and carcinoma of the prostate metastatic to bone.

Acid phosphatase is found increased in carcinoma of the prostate. Generally, but not always, an increased production of acid phosphatase occurs in the blood after this tumor tissue has ruptured through its capsule and has metastasized to soft parts or to bone. This is also true of the alkaline phosphatase but an increase in the acid phosphatase content is pathognomonic of carcinoma of the prostate metastasizing to surrounding or osseous structures. Instances in the purely osteolytic lesions of carcinoma of the prostate in which the acid phosphatase is not elevated do occur, although this is the exception rather than the rule.

To determine the total protein and the albumin-globulin ratio is important. In multiple myeloma almost universally the total protein is elevated; the albumin portion remains approximately normal, while the globulin content increases, resulting in a hyperproteinemia. In this entity it is also necessary to look for Bence-Jones protein in the urine. This may not always be found, but when found, it is highly indicative of multiple myeloma.

TABLE 4

CHEMICAL DETERMINATIONS IN TUMORS AND IN OTHER LESIONS OF THE SKELETAL SYSTEM *

Disease	*Serum Acid Phosphatase*	*Serum Alkaline Phosphatase*	*Serum Inorganic Phosphorus*	*Total Serum Calcium*	*Urine Sulkowitch*	*Urine Bence Jones Protein*	*Total Serum Protein*
Chondroma Osteochondroma Osteoma Exostoses		Normal	Normal	Normal			
Solitary bone cyst		Normal	Normal	Normal			
Giant cell tumor	Normal	Normal or sl. raised	Normal	Normal			
Osteogenic sarcoma	Normal	Usually High	Normal	Normal			
Endothelioma of bone		Normal or sl. raised	Normal	Normal			
Reticulum cell sarcoma of bone		Normal or sl. raised	Normal	Normal			
Rickets		High	Normal or low	Normal or low			
Inflammatory disease of bone		Usually normal	Normal	Normal			
Osteolytic metastatic disease	Normal	Normal or moderately raised	Normal or high	Normal or high	High	Negative	Normal
Osteoplastic metastases not from prostate	Normal	High	Normal	Normal	Normal	Negative	Normal
Carcinoma of prostate metastatic to bone	High in 70% of cases	High	Normal	Normal	Normal	Negative	Normal
Plasma cell myeloma	Normal	Normal or sl. raised	Normal or high	Normal or high		Positive in 60% of cases	Normal to very high
Osteomalacia	Normal	Moderately raised	Normal or low	Usually low	Usually low		Normal or low
Senile osteoporosis		Normal	Normal	Normal	Normal		Normal
Hyperparathyroidism		High	Low	High	High		
Osteitis deformans	Normal	High	Normal	Normal	Normal		Normal

The first eight entries show conditions most commonly found in children and young adults; the remainder show those more frequently found in older patients. Where a space is left blank, detailed studies are lacking, but abnormal values have not been reported.

* From Woodard, H. Q., in Coley, B. L. *Neoplasms of Bone and Related Conditions.* New York, Paul B. Hoeber, Inc., 1949.

TABLE 5

CHEMICAL DETERMINATION IN TUMORS AND OTHER LESIONS OF THE SKELETAL SYSTEM *

Normal Values: Normal † values for the blood and urine constituents commonly studied are as follows:

Serum alkaline phosphatase	*Adults*	Bodansky units 1.5–5.0/100cc. King-Armstrong units 5.0–17.5/100cc.
	Children	From upper adult normal limit to three times this, depending on rate of growth.
Serum acid phosphatase	*Adults*	Bodansky units 0–1.0/100cc. King-Armstrong units 0.6–3.0/100cc.
Serum inorganic phosphorus	*Adults*	2.4–4.0 mg./cc.
	Children	4.0–6.0 mg./100cc.; higher in infants.
Total serum calcium	*Adults*	10.0–11.5 mg./100cc.
	Children	11.0–12.5 mg./cc.
Total serum protein	*Adults*	6.5–8.0 gm./100cc.
Urine calcium		Weak to moderate Sulkowitch reaction, depending on diet.
Urine Bence Jones protein		Negative.

* From Woodard, H. Q., in Coley, B. L. *Neoplasms of Bone and Related Conditions.* New York, Paul B. Hoeber, Inc., 1949.

† Values outside the above limits are occasionally seen in apparently normal individuals; if they are persistent, they should be viewed with suspicion.

Calcium and phosphorus studies should also be made, as these are noticeably altered in hyperparathyroidism, in osteomalacia, and occasionally in plasma-cell myeloma.

Biopsy. Biopsies are absolutely necessary in the diagnosis of any suspected malignant bone tumor. It is true that with the osteochondromata excision of the entire tumor should be done and that with the chondroma of the phalanges and metatarsals and metacarpals resections can be done and definitive surgery completed as the primary procedure in any doubtful case. However, biopsy is mandatory. There are two types of biopsy — aspiration biopsy and open surgical biopsy.

Aspiration biopsy. This type of biopsy has the advantage of being relatively simple. It can be done under local anesthesia and it does not require the large surgical set-up for procedures that open biopsy does. It may be a method by which chronic or acute inflammatory conditions

and true tumors are differentiated. However, many times negative findings are obtained by this method, and this does not necessarily rule out the possibility of a tumor. Also a complete panorama of the tumor itself cannot be seen and cannot be sent to the pathologist for detailed study. Very often one segment of the tumor may look benign whereas another segment appears to be highly malignant. This method, therefore, has a limited use. This type of biopsy was first described by Martin and Ellis (1930). The technic is relatively simple but may require roentgenographic guidance and considerable know-how, especially in those lesions of the vertebral bodies. The technic is quoted as follows:

> The special paraphernalia required is an ordinary 18-gauge needle, 5 to 10 cm. in length (which should be new and sharp), and a 20 cc. Record syringe. For the preservation of the specimen, glass slides and a specimen bottle with 10 per cent formalin are needed.
>
> The skin at the site of the intended puncture is painted with iodine and a small area of skin infiltrated with 1 per cent solution of novocaine. With a bistoury pointed scalped (No. 11 Bard Parker blade) a minute stab wound is made through the skin with the instrument held at right angles to the skin surface. This puncture of the skin facilitates insertion of the needle. An 18-gauge needle attached to a tightly fitting Record syringe is then inserted and advanced slowly through the superficial tissues until the point is felt to enter the suspected neoplastic mass. Guided by palpation with the disengaged hand, it is striking how readily a difference in consistency of the tissues can be felt as the needle enters a mass of neoplasm. When the point of the needle is felt to enter the tumor, the piston of the syringe is partly withdrawn so as to produce a vacuum and the needle slowly advanced 1 to 3 cm., depending on the anatomy and size of the tumor. Maintaining the vacuum, the needle is then withdrawn to the same distance and advanced again. This manipulation may be repeated two or three times at the discretion of the operator, care being taken to maintain the vacuum when the needle is advanced or withdrawn. Aspiration with the needle at rest is not sufficient to draw tissue into the needle in most cases. By advancing the needle and aspirating simultaneously, a plug of tissue is both forced and drawn into the needle. Maintaining suction during partial withdrawal detaches the plug of tissue already within the needle. We have found this detail to be very essential. Before the needle is completely withdrawn from the tissue, the piston must be slowly released until the pressure in the needle is equalized, or better still, the syringe detached and the needle withdrawn separately, otherwise the aspirated material will be suddenly drawn and splashed over the interior of the syringe, making its collection difficult While the needle is being advanced and withdrawn under negative pressure, a small quantity of blood mixed with fragments of tissue may enter the syringe or a solid cylindrical mass of tissue may appear. In other cases, especially in the firmer masses, the syringe apparently remains empty but, after withdrawal, the needle is usually found to contain a plug of tissue.

After complete withdrawal of the apparatus, the syringe is detached from the needle, filled with air, attached and the contents of the needle slowly and carefully expelled on a glass slide. A small fragment of tissue should be left on the slide for smearing and the remainder placed in the specimen bottle for fixation and staining by regular methods. If the needle is empty, small masses of tissue can almost always be found mixed with blood in the syringe and these should, if necessary, be very carefully searched for. One or two of these small masses can readily be fished out upon a glass slide for smearing and immediate staining. In any case where the syringe contains blood or any tissue, formalin from the specimen bottle is poured into the open barrel of the syringe, agitated and returned to the specimen bottle.

Surgical biopsy. This is an open operation and of necessity should be performed in a completely equipped operating room. It has become a valuable practice in recent years to have the pathologist on hand so that he can view all tissues, allowing him to have a gross look at the tissue *in situ* as well as adequate material for his use in the laboratory.

The biopsy should be done by one trained adequately and of professorial rather than resident status. His description and his knowledge should be made part of the permanent record.

A biopsy should precede all amputations for suspected malignant bone tumors. When done correctly, there is little chance of disseminating the tumor. Great care should be used in handling the tissue overlying the tumor. Soft tissue should be draped so that none of the biopsy material can fall into normal tissue and be a possible avenue of extension. The biopsy should be adequate so that the pathologist can have a complete panorama of all segments of the tumor. It is well to take sections from the periphery (labeling them separately), and then go deeper into the tumor and take several sections or a large block and label it so that the pathologist will know all of the various structures with which he is dealing and their relationship to the tumor mass.

Special attention should be given to closure of the wound. The wound should be closed tightly and never allowed to be packed open or drained. Drains or open packing only lead to a release of tissue tension and a wild and rapid growth of the malignant bone tumor. At times the pathologist is able to make a diagnosis by frozen section. It is well, however, to delay definitive treatment until such time as adequate paraffin sections have been made and thoroughly studied.

Final Diagnosis. An adequate history and careful general physical examination along with the necessary roentgen examinations and laboratory data, including adequate blood chemistry, should provide at least a "working diagnosis." No definitive treatment should be carried

out on roentgen evidence alone unless the lesion happens to be at a totally inaccessible area so far as surgical biopsy or excision is concerned. Although after biopsy one has in most instances a working diagnosis, this is not the Supreme Court for in many instances the pathologist cannot be 100 per cent sure of the diagnosis, and the final diagnosis may remain in doubt until the course of the tumor is followed over a long period of time. The differentiation between certain tumors, namely, Ewing's tumor, sympathetic neuroblastoma and reticulum-cell sarcoma, at times is difficult, and only after the course of the disease has been studied can a final diagnosis be made. The more experience one has in the diagnosis and treatment of malignant bone tumors, the less dogmatic he becomes regarding the diagnosis and the degree of malignancy.

BENIGN TUMORS OF BONE

Osteoma

The osteoma (Geschickter and Copeland, 1949) is generally derived from a membranous type of bone and occurs in the skull, jaws, sinuses, and rarely in long bones. It is rarely the problem of the orthopaedic surgeon.

Roentgenographically (Fig. 436), the picture is that of a dense mass of bone with regular outline and no soft tissue swelling.



FIGURE 436. Osteoma of sella turcica. Although benign, this tumor caused the death of the patient by pressure erosion of the circle of Willis. (From Coley, *Neoplasms of Bone*, Paul B. Hoeber, Inc.)

Treatment. Ordinarily these tumors do not require excision, except for cosmetic purposes or when they become a mechanical hazard to the area in which they are found.

Osteochondroma

Solitary (Single) Osteochondroma. These tumors occur twice as often in males as in females and rarely are found in the Negro race. Almost one-third of these tumors occur about the knee joint, either at the upper end of the tibia or at the lower end of the femur. However, they may occur at the metaphyseal end of any long bone. It is a tumor generally arising in adolescence or early adulthood, and generally it comes to light when palpating for a sore point after some trauma to the part draws attention to the tumor mass. The trauma as such is not the cause of the osteochondroma.



FIGURE 437. Osteochondroma of the humerus.

These tumors are often painless in themselves, but they may increase in size slowly until they become large enough so that they impinge on some adjacent structure and cause pain.

Roentgenographically these tumors ordinarily have a broad base

which is confluent with the shaft of the long bone on a pedicle. The external portion of the pedicle flattens out, giving a mushroom appearance (Fig. 437), and is covered with a cartilaginous cap over which one may see an adventitious bursa which often contains fluid. Most of the tumor occurs in the area of the cartilaginous cap, producing perfectly normal looking bone beneath it. The treatment of the solitary osteochondroma is complete excision. A sufficient amount of the surrounding shaft base should be removed, leaving a small concavity in the cortex. If the excision is adequate, there is little or no chance of recurrence.

Multiple Cartilagenous Exostoses. Under this category, many terms have been used, namely, hereditary deforming dyschondroplasia, multiple cartilaginous exostoses, or diaphyseal aclasis. These tumors are characterized by masses of bony tissue found on many flat or long bones and arranged in a roughly symmetrical manner. There is a definite hereditary history.



FIGURE 438. Multiple hereditary dyschondroplasia involving the long bones.

Roentgenographically, there is a widening of the epiphyseal ends of long bones (Fig. 438), appearing early in childhood, and they may by their growth cause distortions of adjacent bone.

Ollier in 1898 described a somewhat related condition (Ollier's disease) and pointed out that this chondroplasia affects largely the upper and lower extremity of the same side, although his original case did not follow this pattern exactly. This condition is discussed in Chapter 2 under Ollier's disease.

There are so many of these tumors that one only advises removal when they interfere with function of the part. When this does become necessary, complete excision of the tumor down to and including its base must be done. While the possibility of malignant degeneration is slight, it is greater in multiple congenital exostoses than in the single osteochondroma. This is obviously so, as there are many more lesions.

Central Chondroma

This is a benign type of tumor composed chiefly of cartilage. When it occurs in the shaft of the small long bones, such as the phalanges, it is called an enchondroma. These tumors are found typically in the small bones of the hands and feet and reach their peak incidence between the twentith and thirtieth years of life. They are very slow growing.

Clinical Picture. Inasmuch as these tumors are slow growing, the history is that of gradually increasing ache or pain in the area involved with or without some gradual increase in the size of the phalanx, or of the metatarsal or metacarpal bone. Many of these never give rise to any discomfort unless the part becomes bruised, and it is not at all uncommon to have them accidentally discovered during a routine roentgenographic examination.

Roentgenographic Findings. The growth in the phalanges produces a central rarefaction which appears on the film as an expanded cystlike area within a shell of cortical bone (Fig. 439). As the tumor grows, this cortical bone may become invaded, but new bone is laid down beneath the periosteum so the tumor may appear to be an expansile one. When these tumors occur at the costochondral junction they appear to be benign microscopically, but they have a higher rate of recurrence than do those in the small bones of the hands and feet. When they are found in the long bones or in the area of the sternum or in the costochondral junction, the prognosis is not as good as that for the chondroma found in the smaller bones of the hands and feet.

Pathology. Grossly the outstanding feature of this type of tumor is the lobulated and gelatinous character of the tissue. The color is pearly white or a light yellow. Microscopically the bulk of the tumor is composed of normal adult cartilage. The cartilage cells lie in pairs

or triads with small lacunae. In the phalanges the microscopic picture is slightly different, with much cellular connective tissue and fetal cartilage intermingled to form myxomatous material. The connective tissue at the margins of these tumors may show definite ossification.

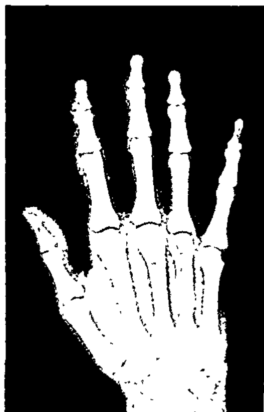


FIGURE 439. Central chondroma of the fourth metacarpal bone.

This ossification may give rise to a somewhat malignant appearance when seen microscopically, but these tumors are almost universally benign. It is always well to tell the pathologist the source of the tissue so that he may keep this in mind when he goes over the pathologic tissue.

Treatment. Surgery is indicated when there is pain or evidence of increase in the size of the tumor mass. Complete curettage of tumor tissue along with packing the cavity with bone chips is the treatment of choice. It may be necessary in the metacarpals and metatarsals to use a long bone strut in order to maintain the length of the bone and also to fill the area around it with bone chips in order to get a better cosmetic and functional result. Unless the tumor is completely removed, there is the possibility of recurrence.

In the central chondroma of long bones, there is the possibility of

secondary chondrosarcomatous changes, so that adequate and thorough biopsy study should be made. When central involvement of the long bone is found in adults, sarcomatous change should be suspected until proven otherwise. Ordinarily, complete removal and use of bone chips is indicated. In some instances, amputation is necessary. Excellent results have been reported (Phemister, 1940) from complete local excision and bridging of the gap by a massive bone graft.

Solitary Bone Cyst

The solitary bone cyst is found in the young age group, usually between the ages of 6 and 18. It is a slow growing, destructive bone lesion presenting few symptoms unless pathologic fracture occurs. Its most frequent sites are the upper end of the shaft of the femur, humerus and tibia and in decreasing number in the ends of other long bones. It appears as a cystic area in the metaphysis of the long bone just adjacent to the epiphyseal line. Ordinarily these tumors do not cross the epiphyseal line. This is in contradistinction to the giant-cell tumor which is found eccentrically placed in the epiphysis after the epiphyseal line is closed.

Clinical Picture. The history generally given is that of a child who complains of pain after a minor trauma to the area of the cyst. Examination shows some slight swelling and palpation reveals what is known as "egg-shell crackling." This is a sensation of cracking the shell of an egg and is produced by minute fractures through the very thin wall of the cortex of the cyst and the surrounding bone. The amount of pain which the patient has is not nearly as great as one would suspect with an ordinary fracture. The trauma generally is minimal and this should suggest this type of lesion even before roentgenograms are taken.

Roentgenographic Findings. Roentgenograms show a single or, at times, a multiloculated central bone defect occurring in the metaphysis just adjacent to the epiphyseal plate (Fig. 440). Whenever one cyst is found one should insist on a complete bone survey to make sure that one is not dealing with a multicystic disease rather than the solitary bone cyst. As stated before, the patient should also be studied from the standpoint of changes in blood chemistry to see if there are any abnormal findings.

Pathology. Grossly there is connective tissue lining these simple bone cysts which often contain a serous fluid. At times a fluid level is demonstrable in the roentgenogram. However, this is not necessarily true. Some cysts show a degenerative mass of tissue which seems to be

undergoing liquefaction. Others of these cysts may have a granular type of lining somewhat akin to that of the giant-cell tumor. However, in contradistinction to the giant-cell tumor, this is a true cyst, whereas the giant-cell tumor is completely filled with a beefy, red material.



FIGURE 440. Solitary bone cyst of the femur. *Left,* before treatment; *right,* same case one year after operation.

Treatment. If there are multiple cystic lesions, surgical intervention is not indicated except for diagnosis or in areas where it is obvious that fracture will ensue if additional bone is not added. In the solitary bone cyst, radiation has nothing to offer in the way of treatment and is definitely a hazard. Because of the proximity to the epiphyseal plate, radiation may cause damage to this part with resulting disturbance of bone growth. There is also the possibility of late development of sarcomatous changes if radiation therapy is used in these lesions.

The treatment of choice is surgical. One must completely excise the lining of the cavity, removing everything down to normal bone. Coley (1949) swabs the area with carbolic acid or some strong cauterant, following which this is removed with alcohol. There are others who believe that this is a definite deterrent to bone growth and,

therefore, do not use this procedure. After thorough curettage and washing with saline, the entire cyst area is filled with bone chips. In some areas, one can actually crush the wall of the cyst and thus stimulate subperiosteal new bone growth. Recurrence of an adequately treated solitary bone cyst is rare. *Solid ossification of the entire area* should be expected.

Benign Giant-cell Tumor (Osteclastoma)

This tumor appears after the closure of the epiphyseal line in most instances. It was formerly called giant-cell sarcoma or benign giant-cell sarcoma. It is a slow growing, central type of benign tumor, expanding the bone eccentrically from the epiphysis and migrating into the metaphysis only by direct extension. It reaches its peak incidence after the closure of the epiphyseal plate and generally before the age of 30. However, the author has observed patients as old as 60 years with this benign tumor. Like bone cysts it may show few if any symptoms until some minor trauma produces a pathologic fracture. This, of course, is followed by pain, deformity and local tenderness.

The bones most frequently involved in this type of tumor are the lower end of the femur, the upper end of the tibia, the upper end of the humerus, and the distal end of the radius. It may appear as a multilocular cystic area eccentrically placed in the ends of these long bones. Statistics show that over 60 per cent of the patients have a history of definite trauma prior to the finding of the tumor. Thus here again, trauma may bring the rather somnolent tumor to light rather than be the causative agent. Those tumors found about the knee joint may give a history of rheumatic-type aches and pains for a long period of time before any definite swelling is discernible and before the patient appears in the physician's office for examination. Those lesions in the nonweight-bearing joints may also produce aches and pains, especially in the upper end of the humerus, where the diagnosis may be subdeltoid bursitis, periarthritis, or frozen shoulder. Many of these patients are treated by injection, radiation therapy, or various modicums of physical therapy before a definitive diagnosis is made. Here it is very important to get adequate roentgenograms prior to the institution of any form of therapy.

This definitely is a lesion of adulthood which comes on after the epiphyseal plate is closed; is eccentrically placed in the epiphysis and migrates to the metaphysis only by direct extension. This is in contradistinction to the solitary bone cyst which is an adolescent and pre-

adolescent lesion which occurs when the epiphyseal plate is still present, being on the metaphyseal side of the epiphyseal plate.

Roentgenographic Findings. Roentgenograms (Fig. 441) show a *multilocular type of tumor growing actively in all directions without*

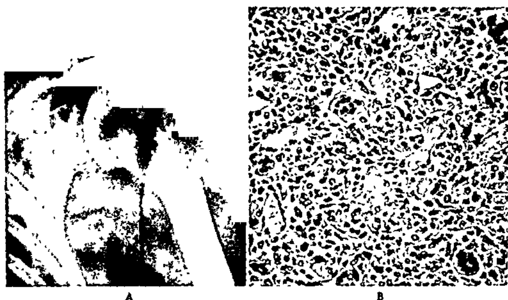


FIGURE 441. (*A*) Benign giant-cell tumor at upper end of the humerus. (*B*) Photomicrograph showing the typical giant cell with nuclei and the round cells predominating in the stroma.

new bone formation and presenting a thin, intact, cortical bone wall with corrugated markings on the inner wall of the tumor. These lines in the roentgenograms give the appearance of a multilocular effect which is very deceiving. The multiloculated effect is secondary to the uneven pressure necrosis which occurs in the cortical bone and gives it this appearance.

Pathology. Grossly the tumors are soft, friable, hemorrhagic tissue that has been described as resembling currant jelly, although it may be of a paler color. Microscopically (Fig. 441B) there are large multinuclear giant cells with a predominant stroma of small round cells.

Treatment. *These tumors are more difficult to treat than the ordinary* bone cyst. The primary treatment is that of wide excision with complete cleaning out of the entire involved area. Following curettage, cauterization of the entire lining of the cavity may be done with carbolic acid swabs and then washed with alcohol. (There are some who believe that this is not necessary and that it is a deterrent to osteogenesis and later healing.) The cavity should then be packed with bone chips, pref-

erably from bone of the host. However, if this is not advisable, bone from a bone bank may be used. In certain areas of the body, where the tumor is very large and in a weight-bearing area, this type of surgery may not be indicated because the necessary curettage and removal of bone weakens the structures so greatly that it predisposes to fracture or multiple fractures. With extensive involvement of the lower end of the femur or the upper end of the tibia, it may be necessary to do an ablation. However, this should be delayed until the former method of approach has been tried and proved to be a failure. In certain nonweight-bearing bones, such as in the upper end of the fibula, a complete excision of the tumor is recommended. This is in an area where the function of the lower extremity will not be impaired and in which the tumor can be excised along with the periosteum, giving less likelihood for recurrence of the tumor. There are certain inaccessible portions of the body in which giant-cell tumors may be found, namely, the vertebral bodies, and in these sites roentgen therapy should be used rather than surgery.

Occasionally there are malignant variants of giant-cell tumors which have been called giant-cell variants. It is not the scope of this book to get into a detailed dissertation on this subject, as authors vary widely in their beliefs. However, ablation would be the method of choice if it were a malignant giant-cell tumor or what is known as a "malignant giant-cell variant."

Osteoid-osteoma

This tumor, first described by Jaffe (1935), is by no means rare and is thought to be a true tumor of bone. It is a small benign lesion affecting a single bone, resembling the sclerosing type of osteomyelitis — very much like cortical abscess of bone. It is more common in males principally between the ages of 10 and 15 years. In more than half of the cases the cortex of the tibia or femur is involved. However, as more and more of these are reported, they have been found in almost any bone in the body.

Clinical Picture. The average clinical picture is that of a patient presenting himself with an extremely persistent and often very severe pain over the affected area. There are frequently few, if any, local manifestations of disease. In fact, swelling, redness, or changes in the skin are strikingly absent. A persistent severe local bone pain should alert the physician to the possibility of an osteoid-osteoma.

Roentgenographic Findings. Roentgenograms often show a relatively

radiolucent area or a nidus within a dense surrounding cortex, suggesting a chronic inflammatory disease (Fig. 442).



FIGURE 442. Osteoid-osteoma of the tibia *Left*, note the small translucent nidus in the thickened cortex *Right*, typical microscopic appearance of osteoid-osteoma.

Treatment. This is considered a benign osteogenic tumor of slow growth, which responds well to surgical removal. Excision of the osteoid-osteoma with its nidus should be complete. No recurrences of the tumor have been reported after adequate extirpation of the nidus. It is noticeable that after the tumor has been removed and almost as soon as the patient awakens from the anesthesia, the pain is entirely gone

Benign Chondroblastoma of Bone

This tumor at one time was identified as a giant-cell tumor variant or "epiphyseal chondromatous giant cell tumor" (Codman). Jaffe and

Lichtenstein (1942) felt that this tumor had no kinship whatsoever to a genuine giant-cell tumor and that it should be regarded as a distinctive tumor. They believed that it should be classified among the benign tumors of bone derived from cartilage cells or cartilage-forming connective tissue.

This tumor generally occurs in the second decade of life and generally is observed in the large tubular bones, namely, femur, tibia and humerus, in that order of frequency.

Clinical Picture. The onset is generally insidious and is generally present some months before it is brought to the attention of a physician. The referred complaints are generally to the affected joint with pain on motion and with a limited amount of swelling and tenderness.

Roentgenographic Findings. Roentgenograms (Fig. 443) generally show a well-delimited rarefied focus in the epiphysis. The lesion is

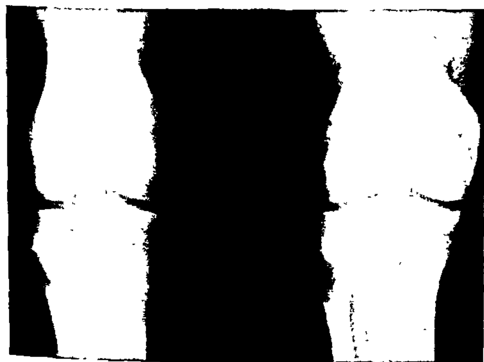


FIGURE 443. Chondroblastoma of the medial condyle of femur. *Left,* before treatment; *right,* same case one year postoperatively.

usually ovoid in contour, is small, and is delimited to the epiphysis, or if large, may invade the adjacent metaphysis. It generally is eccentrically placed and may bulge out into the overlying cortex without destroying it. The lesion is often mottled and fuzzy and encircled with a line of sclerotic bone. The fuzzy mottling is secondary to spotty calcification within the lesion itself.

Pathology. The tumor grossly is usually gray-brown in color and firm. To the touch there is some gritty sensation from the calcification within it. Microscopically multinuclear giant cells may be found, particularly where there has been some hemorrhage. These are the cells which probably accounted for the confusion between this tumor and the giant-cell tumor of bone in the early literature. The striking picture is that of focal areas of calcification throughout the cellular tissue of the tumor.

Treatment. In many of these tumors, the entire area has been curetted out and filled with bone chips prior to the time that an accurate diagnosis is made, as it appeared grossly to be a benign tumor. This still appears to be the treatment of choice. It has been noted, however, in some of the smaller lesions that merely curetting the lesion out has sufficed in restoring the part both anatomically and functionally. Radiation, although it has been used, does not seem a *rational* method of approach, as we still have evidence that radiation may lead to secondary malignant tumors later on. It would seem more rational, therefore, to depend on clean surgery, inasmuch as the results have been excellent under this method of care.

Angioma (Hemangioma)

These tumors are relatively rare and are of two main types: hemangioma of the spine and hemangioma of the long bones.

Hemangioma of the Spine. This may give rise to a persistent ache or discomfort in the back in people over 50. Infrequently, there may be radicular pain or even paralysis due to collapse of the vertebral body.

Roentgenologically (Fig. 444) the vertebral body shows a honeycombed appearance. The vertebral striations seem more pronounced as the bone density has been decreased between them. Most likely the entire vertebra is involved, the involvment being solitary.

Hemangioma of Long Bones. These tumors are more frequent in young adults and are more likely to be multiple. The diaphyseal portion of the shaft is usually involved.

Roentgenographically there are multiple areas of destruction. The bone may be expanded to paper-like thinness. In some cases, there may be the so-called characteristic "soap bubble" appearance.

Grossly, these tumors are hemorrhagic and may resemble currant jelly.

Treatment of Both Types. These are benign tumors and are radio-

sensitive. In the inaccessable areas such as the spine a back support plus radiation usually is adequate. Surgery is very rarely indicated and only then in those cases showing cord compression. Those tumors in



FIGURE 444. Angioma of the body of the third lumbar vertebra. Note the longitudinal striations in the body characteristic of this condition.

long bones may be treated radiologically, or occasionally in the very large tumors surgical removal and use of bone grafts may be used.

Nonosteogenic Fibroma

This lesion was first described by Jaffe and Lichtenstein in 1942. It is a benign bone lesion occurring most frequently in the upper and lower thirds of long bones. It arises from connective tissue of the marrow and usually gives rise to few, if any, symptoms. Following injury or contusion, pain or swelling may develop. In those cases seen by the author, most often these were incidental findings. Inasmuch as they occur very often about the knee joint and in young individuals, it is common to find football players, basketball players or anyone in sports in school or in college injure their knee and thus reveal the condition. Roentgenograms must be taken as part of the examination of such an injury and

the nonosteogenic fibroma may be shown on the roentgenograms as an incidental finding.

Roentgenographic Findings. Roentgenograms reveal several eccentrically placed confluent areas of localized rarefaction (Fig. 445). There

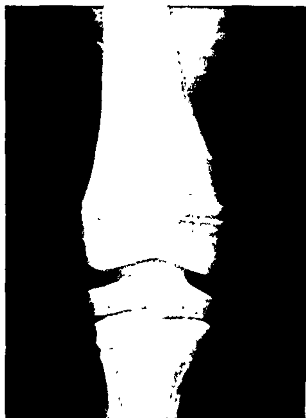


FIGURE 445. Nonosteogenic fibroma of the tibia. Note similar lesion in the femur.

may be surrounding sclerosis It may be mistaken for fibrosarcoma of low grade malignancy. However, the roentgenographic picture is extremely suggestive of nonosteogenic fibroma. If the lesion is in a tubular bone such as the fibula or ulna, the lesion may occupy the full width of the shaft, in which circumstance it might have to be differentiated roentgenologically from a bone cyst or a focus of fibrous dysplasia

Microscopic Appearance. There are essentially whirled bundles of spindle-shaped connective tissue cells with occasional small spindly multinuclear giant cells There may be large or small collections of foam cells observed in places. These are a separate entity. In the past it has been sometimes classified with a giant-cell tumor variant but certainly should not be so

Treatment. Surgical removal is recommended in most instances. In the fibula, complete resection may be the method of choice. This is not a radiosensitive tumor and this form of therapy should not be used. If this tumor is an incidental finding to another injury, periodic roentgenograms should be done at 3 to 6 month intervals and only if and when the lesion shows signs of enlargement should surgery be used.

Chordoma

This is a slowly advancing lesion which arises from the primitive notochord. It is a persistently recurring type of tumor that invades and destroys bone by direct extension. Most of these lesions are found in the spheno-occipital or sacrococcygeal regions. It affects males about twice as frequently as females and may occur at any age.



FIGURE 446. Sacral chordoma. Note the area of rarefaction in the lower portion of the sacrum, which may sometimes be calcified.

Clinical Picture. The most prevalent presenting symptom is that of pain in the lower part of the back or pelvic region. It may be confused with other causes of low back pain. Over a long period of time, as a result of its invasiveness, the pain becomes very severe and distressing.

Roentgenographic Findings. Roentgenograms (Fig. 446) show a

rarefaction or calcification of the bones with some trabeculation, but there are no true pathognomonic radiologic features.

Treatment. The prognosis under any form of treatment is not favorable. Radical surgery has not produced an extremely long survival rate. Inasmuch as this is the only form of therapy that has done much, if any, good, radical complete extirpation should be attempted if at all feasible. The tumor is not considered radiosensitive, but roentgen therapy may give palliative help or some slight relief of pain.

Fibrous Dysplasia

Fibrous dysplasia is a generalized term used for fibrocystic disease in bone characterized by single or multiple areas of fibrous tissue in bone, and is by no means a rare disorder. Coley (1949) believes that the term "fibrous dysplasia" is being used to include several forms of fibrocystic disease that may not be related etiologically. There may be a monostotic form without skin or endocrine disturbances. There may be a polyostotic form with or without the usual skin pigmentation and sexual precocity found in the condition known as Albright's syndrome. There are monostotic forms resembling the solitary bone cyst or the type Jaffe describes as "nonosteogenic fibroma of bone." The latter is



FIGURE 447. Monostotic fibrous dysplasia. Note area of dense fibrous tissue. This is somewhat granular in consistency and grayish red in color.

found most often in the metaphyseal areas of long bones. These bone lesions have their inception in childhood.

Monostotic Fibrous Dysplasia. This is the form most commonly encountered. When compared to the polyostotic form there is a definite absence of skin pigmentation and endocrine disturbance. The lesion is confined to a local fusiform swelling of one bone, involving a rib or a long bone of the lower extremity. These tumors are most frequently encountered about the middle of the shaft of a long bone. The blood chemistry findings in this form are generally within normal limits.

The roentgenographic picture (Fig. 447) offers little that is characteristic to delineate it from other forms of single cystic disease.

Polyostotic Fibrous Dysplasia (Albright's Syndrome). Albright (Albright *et al.*, 1937; Albright and Reifenstein, 1948) stressed the triad of multiple bone involvement, precocious sexual development, particularly in females, and areas of skin pigmentation. It affects females most frequently and is often unrecognized until the third decade, although the age of onset is in childhood. It develops slowly and persists throughout life, affecting predominantly the long bones on one side of the body in the diaphyseal portion. Over the body may be scattered "café au lait" spots. These spots are found in approximately 35 per cent of the cases. There is evidence of precocious sexual development in the female in about 20 per cent of the cases. Although the sexual prococity and skin lesions may first bring the patient for examination, in most instances the patient comes to the physician because of a limp or an aching pain in one of the lower extremities. These lesions may exist for a long period of time without any knowledge that they are present.

Roentgenologically (Fig. 448), there is an expansion of bone with thinning and erosion of the cortex. There may be secondary changes such as bowing or pathologic fracture. These lesions may resemble those of von Recklinghausen's disease, also known as generalized osteitis fibrosa cystica of hyperparathyroidism. The only difference roentgenologically in the two lesions is that with the hyperparathyroidism there generally is associated demineralization of the skeleton.

Treatment. Inasmuch as this disease is polyostotic, some lesions may need attention while others may not. Ordinarily, the spontaneous fractures heal relatively well but the disease continues to progress. Where there is marked bowing, osteotomy plus removal of the cystic lesion and insertion of multiple bone chips is indicated.

Roentgen therapy definitely is not indicated. There have been instances reported wherein roentgen therapy may be followed by chon-

drosarcomatous degeneration or secondary osteogenic sarcomas within 4 to 12 years after fairly heavy treatment of this type.



FIGURE 448. Polyostotic fibrous dysplasia of the tibia and fibula. Note the multiple cystic lesions in tibia and fibula.

Adamantinoma

This is a slow growing lesion, essentially benign, but potentially malignant. It affects young adults between 15 and 35 years of age and particularly Negroes. It is found frequently in the lower jaw (Fig. 449) and even more frequently in the maxilla.

As far as the long bones are concerned, it is a very rare primary bone tumor. It is of orthopaedic interest because almost all of the cases reported outside the maxilla and mandible occur in the tibia. It is a very slow growing tumor. Symptoms, at least at first, are not severe. The patient usually complains of some dull ache in the bone involved with some local swelling and tenderness.

Treatment. This tumor is radioresistant and shows a definite tendency to recur. Radical local surgery is the treatment of choice. Wide bone resection with massive bone transplants seems to be the method

of choice. Recurrences have been frequent following less radical surgery (Anderson and Saunders, 1942).



FIGURE 449. Adamantinoma. This was successfully treated by resection of the mandible. (From Coley, *Neoplasms of Bone*, Paul B. Hoeber, Inc.)

Aneurysmal Bone Cyst

The aneurysmal bone cyst is a solitary lesion which has been so named because of its resemblance to the sacular protrusion of the aortic wall in a true aneurysm. It was first described by Jaffe and Lichtenstein (1942) in a paper concerning the solitary bone cyst. Two of their cases manifested a large cyst of bone filled with a spongy mass of bone channels. The cause of this process is unknown. This process is not nearly as common as giant-cell tumor of bone but it may be one of the tumors which was called the "giant-cell tumor of bone" in years prior to its segregation. In contradistinction to the giant-cell tumor, which is predominantly a tumor of adult life, about two-thirds of these tumors known as aneurysmal bone cysts have occurred in patients less than 20 years of age. Almost any bone of the body may be affected. However, it has been seen most commonly in long bones where it has a predilection for the metaphyseal region.

The important features clinically are swelling and pain over the

affected area. These gradually increase in size and intensity. Occasionally, a vertebra may be involved and signs and symptoms of this may be found secondary to compression of the spinal cord.

Roentgenographic Findings. Roentgenologically, (Fig. 450), this is an expanding lesion, often with sharply demarcated, scalloped borders.

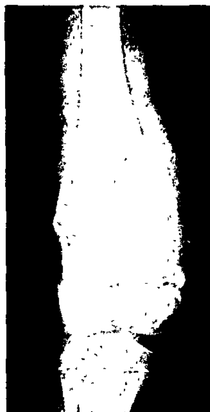


FIGURE 450. Aneurysmal bone cyst in the lower end of femur.

There may be an associated soft tissue extension of the process. There may be a layer of new bone formation limiting the periphery of the tumor.

Pathology. Grossly, there is a thin layer of subperiosteal new bone formation underneath which may be a solid, fleshy or friable type of tissue; beneath this there may be spaces filled with unclotted blood. This blood does not pulsate as the tumor is unroofed. The blood is unclotted so there must be continuous drainage from one end of the bone to the other.

Microscopically, there are generally many cavernous spaces which do not seem to be blood vessels. Solid portions may be fibrous and giant cells may be present in large numbers. This may be one reason this tumor was formerly classified as a giant-cell tumor.

Treatment. It seems that reduction of the supply of blood to the area will stop the progress of this disease. These lesions have been treated either by surgery or by irradiation. The results of both seem uniformly good. There have been cases reported of recurrence but this is exceptional.

PRIMARY MALIGNANT TUMORS OF BONE

Osteogenic Sarcoma

Osteogenic sarcoma makes up the largest group of primary malignant bone tumors. They may be either primary or secondary. Primary osteogenic sarcomas are those originating in the bone as a primary tumor; secondary tumors are those occurring in a pre-existing benign tumor such as an osteochondroma. This group, the osteogenic sarcomas, includes tumors of varying degrees of malignancy, from the very low grade to the very highly anaplastic, extremely malignant tumors. The tumors may be designated by the type of predominating tissue, such as fibrous, sclerosing, osteolytic, or primary and secondary. These tumors arise generally in the metaphysis near the epiphyseal ends of long bones, particularly the femur and tibia, especially around the time that the epiphyses are closing. Predominantly, this is a tumor of adolescence or early adulthood, but it may be found much later on in life. Secondary tumors, or course, are more generally found in later age groups.

Clinical Picture. There is a wide variation in the clinical picture. There may be a very rapidly growing tumor exhibiting a boring type of pain, generally worse at night, with rapidly increasing swelling of the part and with evidence of increase in local temperature and superficial venous engorgement (Fig. 451). The range of motion of an adjacent joint may be rapidly impaired. There may also be a history of weight loss and secondary anemia. These findings from a clinical standpoint indicate a highly malignant type of tumor. Where the onset is not so sudden and abrupt and the pain not so severe, one is usually dealing with a less malignant type of tumor.

Roentgenographic Findings. The lesion may show either bone destruction or bone production (Fig. 452). One of these types of reaction usually predominates, but both may often be seen in the same picture. They usually occur in the metaphyseal ends of the diaphysis at the time when the epiphyseal plate is visible or shortly after it is fused. There may be an increase in bone density above and below the site

affected area. These gradually increase in size and intensity. Occasionally, a vertebra may be involved and signs and symptoms of this may be found secondary to compression of the spinal cord.

Roentgenographic Findings. Roentgenologically, (Fig. 450), this is an expanding lesion, often with sharply demarcated, scalloped borders.

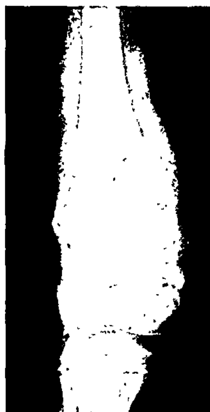


FIGURE 450. Aneurysmal bone cyst in the lower end of femur.

There may be an associated soft tissue extension of the process. There may be a layer of new bone formation limiting the periphery of the tumor.

Pathology. Grossly, there is a thin layer of subperiosteal new bone formation underneath which may be a solid, fleshy or friable type of tissue; beneath this there may be spaces filled with unclotted blood. This blood does not pulsate as the tumor is unroofed. The blood is unclotted so there must be continuous drainage from one end of the bone to the other.

Microscopically, there are generally many cavernous spaces which do not seem to be blood vessels. Solid portions may be fibrous and giant cells may be present in large numbers. This may be one reason this tumor was formerly classified as a giant-cell tumor.



FIGURE 452. (*a*) Osteogenic sarcoma of the femur. (*b*) Osteoid trabeculae surrounded by a profusion of malignant osteoblasts.

of the lesion with scattered areas of rarefaction. The periosteum may be stripped up, often giving rise to subperiosteal new growth of bone which has been described as Codman's triangle. There may be a laying down of radiating spicules of bone at right angles to the shaft of the bone, the so-called "sun ray" or "whiskered" appearance.

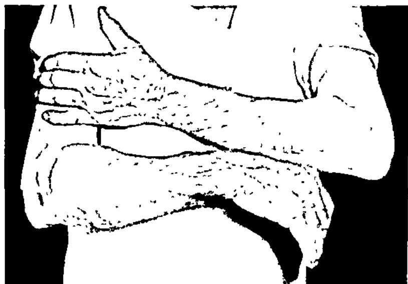


FIGURE 451. Osteogenic sarcoma in right forearm. Note swelling and venous engorgement.

Inasmuch as other types of tumor may give a somewhat similar picture, it is advisable to biopsy the lesion before treatment is undertaken. Too many mistaken diagnoses have been made by roentgenogram and too many limbs have been amputated without biopsy beforehand. The physician should not rely on frozen sections for diagnosis; rather, preliminary biopsy should be done followed by adequate paraffin sections. Only after this should one proceed with the definitive type of treatment.

Prognosis. The prognosis is poor regardless of the type of treatment. *Immediate ablation* of an extremity for osteogenic sarcoma gives an extremely poor prognosis. In the University of Pennsylvania Hospital prior to 1944, 9 patients with osteogenic sarcoma were treated by this method. All died of their disease, the average time being 18 months or less. Following the article by Ferguson (1940) we embarked on a project in which varying amounts of radiation were given prior to ablation. Seven patients were so treated. The shortest survival time was 23 months, the longest survival time of those now dead, 70 months. Of the 3 patients still living, the shortest period since treatment is 4½ years; the longest, almost 10 years.



FIGURE 453. Periosteal fibrosarcoma. *Left,* the roentgenogram shows a faint periosteal tumor and erosion of the cortical and cancellous bone. *Right,* characteristic herringbone pattern of nuclei. (From Geschickter and Copeland, *Tumore of Bone,* J. P. Lippincott Co.)

In this type, many patients can be cured by radical surgery, such as local resection.

Chondrosarcomas

This type of tumor may arise in any bone that grows through enchondral ossification, arising either centrally or peripherally. The chondrosarcoma may be differentiated into primary chondrosarcomas, which are true primary tumors of bone, and secondary chondromas, which arise in the benign tumors, either from a chondroma or an osteochondroma, or from one of many multiple cartilagenous exostoses.

Primary Chondrosaicomas. This tumor is of cartilagenous derivation (primary chondroblastic sarcoma) and generally appears in a later age group than the primary osteogenic sarcoma. It reaches its peak incidence in the midthirties but may be found in earlier or later age groups. Aegerter and Kirkpatrick (1958) state, "It is quite unusual in patients under 30. After 35 the incidence rises progressively and occurs very similarly to that of carcinoma."

Chondrosarcoma seems to be a relatively slow growing tumor which may require several years to manifest itself. They may occur centrally

The series is relatively small but impressive. Fortunately, the disease is not too common. There seems to be a very definite trend to survival in our series in those who had preoperative radiation; first, as to length of survival and, second, as to survival. Therefore, until there is a better method of approach we will continue to administer radiation prior to ablation in the treatment of this highly malignant tumor.

Secondary Osteogenic Sarcoma of Bone

This is a tumor which arises in a pre-existing benign tumor and usually appears later in life than the primary osteogenic tumor. These tumors are generally not so rapidly growing or have so poor a prognosis as primary osteogenic sarcoma.

Treatment. The treatment is identical with that of primary osteogenic sarcoma except that if the site is suitable, one might consider local, complete excision rather than ablation.

Fibrosarcomas of Bone

These tumors, although malignant, should be placed in a separate group from the osteogenic sarcomas inasmuch as they have a better prognosis.

Pathology. Microscopically, the picture is the same as that found in a fibrosarcoma arising elsewhere in the body. The malignancy can be graded by the predominating cells. They also metastasize to the lungs and rarely to the regional lymph nodes. There are essentially two forms of fibrosarcoma.

Periosteal Fibrosarcoma. These tumors show a marked variation in the degree of malignancy. Microscopically (Fig. 453), they are of spindle-cell type which arise from the outer layers in the periosteum and are, therefore, nonbone-forming tumors. Bone involvement by direct extension from the soft parts is often wrongly interpreted as a primary osseous lesion. These tumors have a predilection for the lower end of the femur and the upper end of the tibia, affecting chiefly adults with the peak incidence at approximately 30 years of age. The morphologic picture is one of fibroblasts, spindle cells and small oat-shaped cells. Amputation is the treatment of choice.

Medullary Fibrosarcoma. This form occurs less frequently than the periosteal type. It is most common in the shafts of the long bones near the epiphyseal line. The roentgenologic appearance is so varied that the character of the tumor cannot be predicted from this study alone.

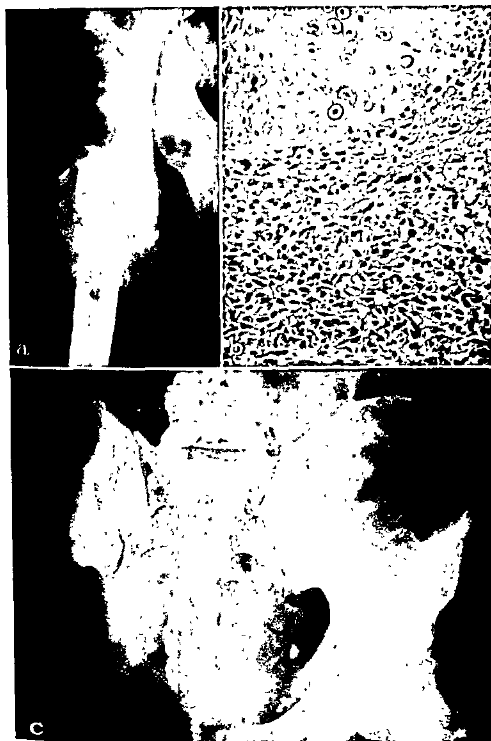


FIGURE 454. Secondary chondrosarcoma. (*a*) Note rapid bone destruction. (*b*) Microscopic appearance of same case. In this section the upper area might suggest a benign process, but the remainder of the section shows myxomatous areas with spindle-shaped or stellate cells characteristic of malignancy. (*c*) Same case following hemipelvectomy.

in long bone or may arise from the outer bone and cartilagenous surfaces. They generally begin in the metaphyseal region but may start in other portions of the shaft to a greater extent than osteogenic sarcoma. Some of these tumors may be highly malignant and grow rapidly, destroying both cortical and cancellous bone in the later stages of its development.

Only when the cartilage starts to ossify does it become visible on the roentgenogram. There is really no characteristic picture. At times there may be an increased ossification along with a soft tissue mass.

Treatment. The tumor is not sensitive to roentgen therapy but radiation may cause regression when used palliatively and there may be some relief of pain. The prognosis is much better than that in osteogenic sarcoma and for that reason more radical surgery would seem to be indicated. By this we mean that the lesion which was a chondrosarcoma in the area of the hip might lend itself to a hemipelvectomy, whereas if the same tumor were an osteogenic sarcoma with a much poorer prognosis, it might not be attempted.

Secondary Chondrosarcoma. Secondary chondrosarcomas (Fig. 454) are generally found between the ages of 35 and 60, males being affected more frequently than females. These tumors generally arise in a pre-existing chondroma or osteochondroma. The prognosis in the secondary chondromas is much better than that in the primary chondrosarcomas.

Although amputation is the treatment of choice, block excision of the tumor along with the surrounding bone structures may be attempted. In either event it must be radical rather than conservative surgery.

Endothelioma of Bone (Ewing's Tumor)

This tumor was first called a round-cell sarcoma of bone. Later it was typified as endothelioma of bone, Ewing's tumor, or Ewing's sarcoma, being first described by Ewing in 1921 (Ewing, 1940). Prior to this time it had been catalogued in a wastebasket of malignant tumors. The majority of these tumors occur in people under 20 years of age, although it has been reported in a child 2½ years of age and in an adult 66 years of age. Forty per cent of these tumors occur in the femur or tibia, generally being located in the shaft rather than the ends of long bones However, it has also been noted in the scapula, pelvis, ribs and spine. Flat bones and soft tissues have also been affected.

Clinical Picture. This tumor presents many of the clinical features

microscopic examination as it will alter or confuse the histologic picture.

Metastases occur in the lungs, skull, vertebrae, and other long bones, and at times in the lymph nodes and abdominal organs. Whether this



FIGURE 455. Ewing's sarcoma. (*A*) Note the slight expansion of the shaft and thickening of the cortex with the "onion peel reaction." Later this becomes much more marked and there is an increased density of the whole tumor shadow simulating an infectious process. (*B*) Note characteristic round and oval nuclei.

is a primary tumor of one bone or a multicentric tumor is problematical. The prognosis is poor. The average survival period after first recognition of the disease is approximately 2 years.

Treatment. This tumor is sensitive to roentgen therapy. There is considerable discussion as to exactly how these tumors should be treated. Many advocate radiation prior to surgery, ablation being the method of choice. Survivals following roentgen therapy and radical surgery are not much greater than that with roentgen therapy alone. In fact, the figures approximate themselves. Pathologic fracture (Fig. 456) does occur and one may wish to avoid weight bearing in long bones until evidence of the tumor regression is present on roentgenogram.

of an infection and is often mistaken for osteomyelitis. It simulates a low grade osteomyelitis, with local heat, slight elevation of temperature and an increase in the white blood count ranging from 10,000 to 15,000. In the later stages the temperature may reach 103° to 104° F. Thus clinically, at times, the tumor is hard to differentiate in its early stages from a low grade osteomyelitis of Garré. The clinical pictures are similar: low grade fever, leukocytosis, and pain in a bone with local tenderness. The osteomyelitic processes generally are in the metaphyseal end of the bone whereas ordinarily Ewing's tumor is found in the midshaft of the bone. However, Ewing's tumor may be found in either site. In either picture we may see normal hemoglobin determinations or mild anemia with local tenderness, pain and tumefaction.

Roentgenographic Findings. The roentgenologic picture (Fig. 455a) generally shows a lesion near the midshaft of a long bone with an increased density and a widening of the shaft. The cortex is generally well preserved. Most often there is a definite periosteal reaction, looking somewhat like "onion peel" formation. The cortex may be mottled in the region of the medullary cavity, and increased density noted in the region of widened cortex, indicating infiltration of the tumor. Although the so-called "onion peel" appearance is allegedly typical of the Ewing's tumor, one may see this appearance in one portion of the bone and in another portion, on roentgenogram, radiating spicules of bone which allegedly are typical of osteogenic sarcoma.

Pathology. This tumor may simulate a reticulum-cell sarcoma of bone or a neurogenic blastoma. At times the pathologist cannot discern miscroscopically the difference in these tumors. Microscopically, there are small polyhedral cells in a compact area with round or ovoid nuclei and scanty cytoplasm (Fig. 455b). The other small round-cell tumors may look strikingly similar in different phases of their growth. One may suspect this tumor from the combined results of physical examination, location of the tumor, age group, and roentgenologic findings. In most instances, however, a biopsy should be done. Here again, aspiration biopsy will not suffice and open biopsy should be done. The pathologist has enough trouble delineating this tumor without asking him to do this from a frozen section alone Adequate paraffin sections should be available to him. Many instances are encountered in which even with the best sections the diagnosis of Ewing's tumor has been made and after the clinical course of the disease has been followed for many years, a change in diagnosis from Ewing's tumor to reticulum-cell sarcoma has been made. It is wise never to use radiation prior to the

an inflammatory process as it does in Ewing's tumor, in which there may be a leukocytosis and an increase in temperature.

Prognosis. Prognosis in this tumor is definitely better than that in Ewing's tumor. Local roentgen therapy generally suffices to handle the local lesion. Other bones may become involved which also lend themselves to roentgen therapy. As more and more metastases occur, the roentgen therapy becomes less effective and the prognosis poorer. Roentgen therapy rather than ablation or local resection, however, is the treatment of choice.

Sympathetic Neuroblastoma

This is generally seen in infancy or childhood. It may arise either as a *neuroblastic tumor of adrenal origin or from the thoracic or abdominal* sympathetic chain. This tumor very often metastasizes to bone and in about 40 per cent of the cases is roughly bilateral and symmetrical. It may, however, occur in one or more locations. This is not a common type of tumor, but is significant because of its similarity histologically to Ewing's tumor and reticulum-cell sacroma of bone. Roentgenologic studies may also show a striking similarity.

Treatment. The ultimate prognosis is very unfavorable. The tumors are radiosensitive. However, the tumor may be so multiple that life expectancy is poor. There occasionally have been spontaneous regressions noted in some of these tumors, but most of them lead to an early demise.

Multiple Myeloma

Multiple myeloma may be differentiated into the plasma-cell myeloma, the myelocytoma, and the lymphocytoma and the erythroblastoma. Inasmuch as the last three named types constitute 5 per cent or less of all of the myelomas, and inasmuch as they have a very similar course, we will consider these as multiple myelomas of the plasma-cell type.

This probably is not a true bone tumor, but is rather a highly malignant growth originating from cells found regularly in bone marrow. It generally produces extensive multiple bone lesions with which may be associated changes in the central nervous system, blood stream, lungs and kidneys. This disease affects predominantly males, the great majority of which are over 50 years of age. Occasionally one bone may be involved in what is known as a "solitary plasma cell myeloma." The tumor consists of plasma cells supported by a delicate reticulum.



FIGURE 456. Ewing's sarcoma before (*left*) and after (*right*) pathologic fracture.

Reticulum-cell Sarcoma

This is a relatively rare malignant tumor of bone which grows fairly rapidly, metastasizing to the lungs and, to a less frequent extent, to the lymph nodes. This tumor usually involves the shaft, but may also invade the ends of long bones, giving rise to extensive bone destruction. Some pathologists have regarded it as a variant of Ewing's tumor, and one may have trouble differentiating it from that entity. This tumor may occur at any age. It is found frequently in young adult life, and when found in patients under 30 years of age, its differential diagnosis from Ewing's tumor is difficult. If it occurs over this age group, it probably is a reticulum-cell sarcoma rather than a Ewing's tumor. The reticulum-cell sarcoma of bone also must be differentiated from the reticulum-cell sarcoma which begins in lymph nodes and metastasizes to bone. However, the clinical picture is closely allied

Clinical Picture. Ordinarily, the patient's earliest manifestation is pain, frequently of a boring type, and worse at night. There may be swelling of the part involved, but there also may be no local heat and no tenderness. The blood count ordinarily does not follow that of

palliative measure to control pain. Pathologic fractures may heal under adequate splinting and protective measures plus deep roentgen therapy.

LESIONS SIMULATING PRIMARY TUMORS OF BONE

There are three granulomatous lesions which bear a close relationship and may represent gradation, at least clinically, of the same basic disorder.

Eosinophilic Granuloma

This disease occurs ordinarily in childhood and adolescence, occurring either as multiple or single lesions (Lichtenstein and Jaffe, 1940; Platt and Eisenberg, 1948). It is a benign lesion found most frequently in the male. Inasmuch as some of these lesions may be multiple, it is imperative that a bone survey be done as in any other type of cystic lesion of bone. The bones most commonly affected are the ribs, scapula, ilium, femur, and skull.

Clinical Picture. The symptoms which ordinarily bring this lesion to the physician's attention are mainly pain and, to a lesser degree, swelling and dysfunction. There may be a moderate leukocytosis and a mild eosinophilia. However, these findings may be lacking.

Roentgenographic Findings. The roentgenographic study generally shows a wholly osteolytic lesion with radiolucent areas of roughly circular shape (Fig. 458). They may appear circumscribed and punched out. Occasionally, there may be reactive subperiosteal new bone formation which may simulate an osteolytic osteogenic sarcoma, Ewing's tumor, osteomyelitis or a simple solitary bone cyst. From a histologic picture, it is fairly easy to differentiate this tumor by open biopsy.

Treatment. If the lesion is solitary, the affected area of bone may be cleaned out by curettage at the time of biopsy. Ordinarily, only a biopsy is done and after the skin and soft tissues have completely healed, roentgen therapy in small doses is administered. Under this regime the local lesion gradually fills in. If the lesion is multiple and one of them is biopsied, then the seconday lesions may be adequately treated with roentgen therapy. The prognosis in a solitary lesion is excellent. The more multiple the lesion, the poorer the prognosis.

Hand-Schüller-Christian's Disease (Lipogranulomatosis)

This syndrome is closely allied to eosinophilic granuloma. It occurs

The lesions may be found in the ribs and sternum as well as in the vertebrae, skull, femur, pelvis and humerus. The tumor begins in the marrow cavity, expanding and replacing normal bone marrow. The gross appearance of the tumor varies in color depending on the vascularity.

Clinical Picture. Pain is a predominant feature. It may be insidious at its onset and is associated with fatigue and anemia. Minor trauma may produce pathologic fracture in a long bone or a vertebral body.

Ordinarily, there is a reversal of the usual albumin-globulin ratio. In approximately half of the cases Bence-Jones protein may be found in the urine. If it is present it is a good diagnostic aid. If it is absent, it does not exclude the possibility of multiple myeloma.

Diagnosis can usually be made by a punch bone marrow biopsy. The usual site for this biopsy is the iliac bone or the sternal bone. Surgical biopsy is rarely necessary.

Roentgenologically, we may see multiple discrete radiolucent areas which appear as areas of punched-out bone (Fig. 457).



FIGURE 457. Multiple myeloma of skull and femoral shaft, two of the many areas involved in this case.

Prognosis. The prognosis is universally unfavorable and no known proven cure has been recorded.

Treatment. Deep roentgen therapy in moderate doses is used as a

Treatment. Because of the multiplicity of lesions, surgery is of no curative value. These lesions respond to relatively small doses of roentgen therapy with the restoration of destroyed bone. The prognosis is fairly good.

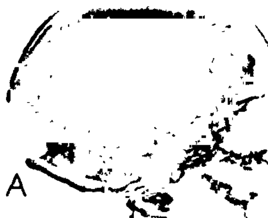






FIGURE 459. Hand-Schuller-Christian's disease. Note the maplike appearance of skull (*A*) and swelling of frontal region (*B*). (*C*) The patient following roentgen therapy. (From Coley, *Neoplasms of Bone*, Paul B. Hoeber, Inc.)

Letterer-Siwe's Disease

This disease is very similar to eosinophilic granuloma and Hand-Schüller-Christian's disease, except it occurs in infancy and generally is rapidly fatal. Both skeletal and soft parts are affected. It rarely occurs after 2 years of age.

ordinarily in infants and children, but occasionally in adults. It is characterized by defects in membranous bone, especially the skull. Clinically, the patient may have excessive thirst, exophthalmos, and at



FIGURE 458 *Left*, eosinophilic granuloma of the upper end of femur. *Right*, eosinophilic granuloma of skull in same patient.

times gingivitis and loosening of the teeth. Bouts of fever and anemia may occur and there may be muscle and joint pain which at times simulates rheumatic fever.

There are frequently many bone lesions, the skull being the most common site. The pelvis, long bones, maxilla, scapula, ribs and vertebral bodies are involved in varying degrees. When the skull is involved there may be actual bulging and tumor formation (Fig. 459). When these areas are pronounced the term "geographic skull" is used. Any portion of the skull may be involved and usually both inner and outer tables are destroyed. When there is involvement of the sella turcica the pituitary gland may function abnormally with resulting symptoms of diabetes insipidus and other endocrine disorders.

Roentgenographic Findings. These studies may show a punched-out area of bone or bones, irregular in size with sharply defined borders (see Fig 459A). They may simulate very closely the metastatic skull lesions found in carcinomata or those of multiple myeloma.

The age incidence, however, should help in differentiating these separate syndromes. Microscopic study shows the typical foam cells scattered in groups or clumps in a meshwork of granulomatous tissue.



FIGURE 460. Paget's disease of the tibia. Thickened cortex has motheaten appearance.

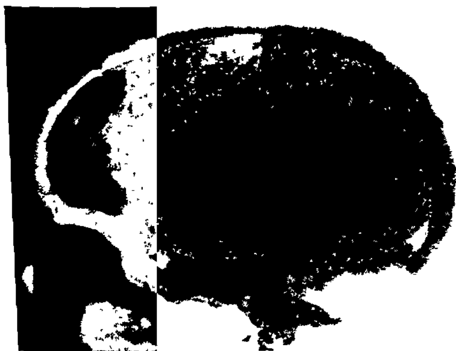


FIGURE 461. Paget's disease of the skull.

Clinically, there may be a purpuric skin rash, fever, and severe anemia. There also may be noted an enlargement of the spleen and lymph nodes, and in some instances areas of bone destruction apparently identical to those found in Hand-Schüller-Christian's disease. Some authorities believe this tumor to be an earlier and more malignant form of Hand-Schüller-Christian's disease.

Osteitis Deformans (Paget's Disease)

Osteitis deformans was first described by Sir James Paget in 1876. Its main orthopaedic interest lies in the remarkable deformation of bones, particularly the skull, pelvis, femora and tibiae. It is usually observed in patients over 40 years of age (Newman, 1946). It was Paget's original idea that osteitis deformans was the result of chronic inflammation of bone. However, this has been conclusively disproved, and though many theories have been advanced as to its causation, the question is still unsolved.

Clinical Picture. The early signs and symptoms may be confused with a number of other conditions. Frequently there is a rheumatic type of ache existing over one or more bones for a long period of time before the patient comes to a physician for aid. As the disease gradually progresses one may find bowing of the tibia or femur, or an increase in the patient's hat size which may give us a lead as to what is going on as far as the osseous structures are concerned.

Roentgenographic Findings. There may be a thickening and broadening of the cortex of the long bones (Fig. 460) with a remodeling of the cortical structures. When the vertebrae are affected they may give the appearance of vertebral metastases of a malignant tumor, such as a carcinoma of the prostate. There may be curving of the long bones with transverse lines of rarefaction in a thickened cortex. These are situated in the convex side of the bone and probably represent incomplete fractures which may occur following slight trauma. The skull may show typical changes (Fig. 461). There may be a roughening and fuzziness which is sometimes designated as a "cotton wool" appearance.

Blood Chemistry. Calcium and phosphorous determinations in this syndrome are nearly always normal. Calcium may be slightly higher than normal, but it never reaches the level found in von Recklinghausen's disease. The alkaline phosphatase is usually markedly increased. The acid phosphatase is usually normal, in contradistinction to that found in carcinoma of the prostate.

Aegerter and Kirkpatrick (1958), "There is an excessive production of histiocytes, most of which become filled with a complex lipid and a cerebroside known as kerasin. Aggregates of these cells accumulate in the spleen, liver, bone marrow and skin." Its relationship to orthopaedic surgery is rare, but bone pain is a prominent feature and inasmuch as it also may be accompanied by fever it may be confused with an infectious bone process.

These roentgenographic features are a combination of absorption, decalcification and sclerosis. The lesions predominately are radiolucent. Almost any bone may be affected but involvement of the bones of the hands, feet, and cranium is rare. Femoral involvement (Fig. 462) is



FIGURE 462. Gaucher's disease. Note so-called "Erlenmeyer flask" appearance of the lower femoral shaft. (From Coley, *Neoplasms of Bone,* Paul B. Hoeber, Inc.)

Prognosis. The changes found in Paget's disease in bones are fairly frequently seen, and usually only a single bone is involved. The appearance of sarcomatous changes at the site or sites of the lesion must constantly be kept in mind. With multiple skeletal involvement the complication of sarcomatous degeneration approaches 10 per cent, whereas in the isolated localization of Paget's disease this complication is nearer 2 to 3 per cent of cases.

Treatment. The treatment of this disease at the present time is empirical. Often one may be dealing with fractures through a pathologic type of bone which at one stage is very hard, dense and brittle. In other phases of the disease the bone may have large vascular spaces which bleed profusely, at which time it is relatively easy to perform an osteotomy. The treatment is quite similar to that used for fracture of bones elsewhere, except that the time of healing is much greater. The fracture lines seem to remain even longer than the clinical symptoms, and very often one seems to have a clinically completely healed fracture which by roentgenogram still shows a fracture line through the pagetoid type of bone. Osteotomy for correction of severe bowing may at times be desirable.

Von Recklinghausen's Disease

This disease is discussed in Chapter 2, page 93.

Disorders of Faulty Lipid Metabolism

Niemann-Pick's Syndrome. This disease is a very rare familial, congenital disorder which begins insidiously in infancy and is generally accompanied by abdominal, liver, and spleen enlargement. There is generally a gradual mental and physical decline resulting in death within 12 to 18 months. This disease is found within a relatively few months after birth, the infant refusing food. The skin appears dry and waxy and there is an accompanying pigmentation of a yellow-brown color. There may be accompanying osteoporosis of the long and cranial bones. One very seldom sees this disease in orthopaedic practice.

Gaucher's Syndrome. This disease is characterized by an insidious onset with chronic anemia, enlargement of the spleen and liver, and a tendency to bleed from the gums. There may be areas of skin pigmentation appearing in patches There is ecchymosis from the slightest trauma. This is also a very rare disease, but is seen more frequently than Niemann-Pick's syndrome and does show bone changes. This syndrome may also be called cerebroside reticulocytosis. According to

(discussed in Chapter 2) must be considered in a study of bone lesions simulating primary tumors of bone. It bears a close resemblance to periosteal osteogenic sarcoma, clinically and roentgenologically. The favorite sites for the *local form* of myositis ossificans are the elbow, thigh (Fig. 463) and shoulder — always following trauma.

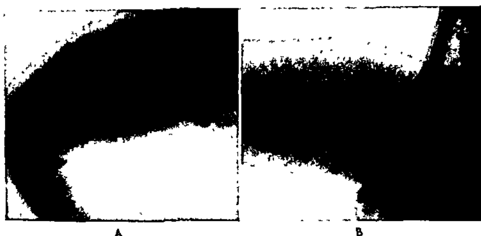


FIGURE 463. Myositis ossificans. (*A*) Simple fracture of upper femoral shaft and (*B*) tremendous callus (myositis ossificans), which developed with inadequate immobilization of this fracture. This resembles somewhat a malignant lesion.

In the first few weeks of its appearance there is an osteoblastic activity as evidenced by fuzzy periosteal proliferation in the roentgenograms; early ossification makes differential diagnosis difficult. The history of onset and the absence of any abnormal blood chemistry changes usually suffice, though at times a punch biopsy in this early phase may give helpful information in deciding between the two conditions.

Later, when the roentgenogram shows the clear-cut outlines of the calcified mass and the absence of any active bony proliferation, the picture is so characteristic of myositis ossificans traumatica that the roentgenologist has no difficulty in making the distinction.

There have been reported a few cases of the late transition of a benign myositis ossificans traumatica into malignant osteogenic sarcoma (Coley, 1949).

METASTASES TO BONE

Skeletal metastases from other tumors occur at least two or three times as frequently as do primary tumors of bone. Primary malignant lesions originating in the breast, bladder, ovary, thyroid and the gastrointestinal tract are common. It is, therefore, very important that one

most common and when one sees the expansion of the distal diaphysis in the femur, it is what is known as the Erlenmeyer flask. This is the typical appearance of Gaucher's disease in bone. There is no known method of cure.

Lipochondrodystrophy. This rare entity is also known as Hurler's disease of gargoylism. This disease begins in early childhood, causing skeletal deformity, especially of the facies. There is most frequently failure of mental development, enlargement of the liver and spleen, and blindness. The skeletal changes vary widely but generally are seen early in life and may be of diagnostic significance. The cranial bones may be thick and dense and enlarged in the anteroposterior diameter. The sella turcica may be shallow and elongated. The ribs may be broad and blunt and the clavicles short and thick. Characteristically, there is a gibbous in the upper lumbar or lower dorsal vertebra with wedging of one or more of these vertebra. The epiphyseal centers may be flat and irregular. The medullary cavity may be widened. The bones of the upper extremity may show more involvement than those of the lower extremity. In each instance, such as the ribs or clavicles, the bones are short and thick. This same picture may also involve the phalanges. Because of the irregularity of the growing ends of long bones, it may be somewhat similar to achrondroplasia or another of the osteochondrodystrophies. The prognosis in this disease is extremely poor.

Infections of Bone

Even before and after the advent of the antibiotics, infections of bone are occasionally confused with bone tumors. We still see occasional osteomyelitis in nontypical forms which may be confused with some tumors. The persistent aching pain in the long bones of osteoid osteoma may be confused with Brodie's abscess or the sclerosing type of osteomyelitis of Garré.

Even with today's adequate treatment of syphilis, a few instances of this infection are confused with bone tumors, and must be considered in the differential diagnosis between this entity and bone tumor. When one suspects syphilis, the serologic test is of great help, but here again it is not a complete diagnostic test.

In the tertiary stages, osseous changes, such as Charcot's joint, frequently occur, but the history, physical findings and roentgenologic appearance generally identify it from any bone tumor fairly readily

Myositis Ossificans

It is pertinent to stress the fact that myositis ossificans traumatica

may be much farther advanced than the roentgenologic evidences of this lesion would suggest. Fractures of the spine should be cared for by some supportive device as well as by whatever roentgen or chemotherapeutic agent is indicated.

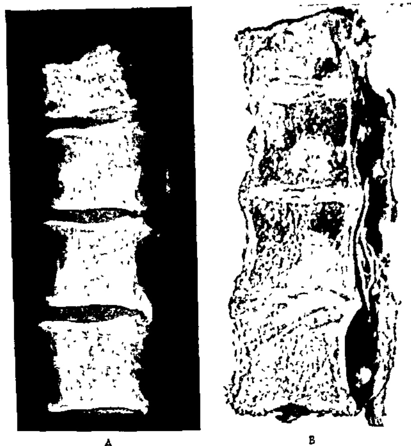


FIGURE 464. (*A*) Pathologic compression-fracture of the body of the top vertebra, with scattered lesions in the other vertebrae. (*B*) Postmortem section at the same level demonstrates the extensiveness of the pathologic lesions, some of which are barely discernible in the roentgenogram. This is important to remember when tempted to base final conclusions on the film alone.

As far as caring for a pathologic fracture of a long bone (Fig. 465), it should be treated as fractures elsewhere. In the shaft of the femur or humerus such fractures may be treated by the use of intramedullary nails.

In the neck of the femur or in the trochanteric area, if not too greatly involved, the usual type of pin fixation is desirable, both for fixation and for simplification of nursing care (Fig. 466). One should also use the necessary roentgen therapy and/or chemotherapy.

Many of these lesions may be discovered prior to the time of pathologic fracture. One of the most frequent tumors is carcinoma of the

delves into the history of the patient as to prior operations and the diagnoses for which these operations have been done. It is not enough to find out when the patient had an operation for carcinoma of the breast.

The patient consults the physician because of pain associated somewhere in the skeletal system. This may be noticed without any previous warning, or it may be antedated by pain in the arm, leg or back, or elsewhere in the skeletal system. The spine, pelvis, femora, and humeri are the usual sites of metastases, in the order named.

The orthopaedic surgeon sees many of these lesions. Recently a man was seen with some pain in the area of the right elbow and forearm, along with pain in the area of the right hip. He had been treated for arthritis of the neck with injections of hydrocortisone. This man had a metastatic lesion not only at the seventh cervical vertebra, but in the right upper femoral shaft and, although asymptomatic, in the left upper femur as well. Another instance occurred recently in a woman who was seen with a diagnosis of a ruptured intervertebral disc. On further examination it was found she had a lesion at the fifth lumbar vertebra which appeared metastatic. Bone survey showed she also had lesions in the skull and a questionable lesion at twelfth dorsal vertebra. Although the patient denied any operations except that of a D. and C., she had a scar from a left radical mastectomy which was done a year and a half previous and a review of the sections showed a malignant breast lesion. Another patient being seen for low back pain had positive findings by myelogram between the fourth and fifth lumbar vertebra, but fortunately an operation was not performed because his symptoms subsided with bed rest and the use of a brace. Later he developed a full-fledged lesion at the fourth lumbar vertebra and in the upper portion of the left femur, the final diagnosis being hypernephroma. Another patient, male, had a compression fracture of a vertebral body He appeared for examination some 6 to 8 weeks after his trauma only to find this was not a traumatic fracture but a pathologic one secondary to a bronchogenic carcinoma.

It is obvious, therefore, that a complete clinical history is necessary, that many of these tumors metastasize early, but some fantastically late. Carcinoma of the thyroid or kidney especially may metastasize to the skeletal system many years after one has an apparent clinical cure from the primary lesion.

Complications may occur with a pathologic fracture in an affected long bone, or when the lesion is in the spine (Fig. 464). The metastases

prostate, which so frequently metastasizes to the lumbar spine. Certainly orchidectomy plus the use of estrogenic hormones is indicated, because many of these lesions require a long period of care prior to pulmonary metastases and death.

Carcinoma of the Breast

This probably is the most frequent primary soft tissue tumor metastasizing to bone. *These metastatic bone tumors generally occur in the* same age group as carcinoma of the breast, but may occur much later. Approximately 30 per cent of these cases metastasize to one or more bones. Most of these lesions become multiple, but when first seen there may be only a solitary lesion. These lesions are seen chiefly in the vertebrae, femora, pelvis, ribs, scapula, and skull. Most of the lesions are osteolytic and only occasionally do we see evidence of sclerosis on a roentgenogram. These lesions attack the long bones toward the proximal end, producing destruction, with little evidence of repair, and frequently produce pathologic fractures.

Treatment is indicated as mentioned before. The prognosis is extremely poor. However, the patient may be made more comfortable by adequate bracing in some areas and by adequate fixation in other areas if there is a pathologic fracture. The use of the male sex hormone or surgical or roentgenologic castration in these instances may delay the ultimate outcome.

Carcinoma of the Kidney

It is in this type of tumor, which is a hypernephroma, that frequently one sees the metastatic lesion prior to the time the primary lesion is seen. These tumors have a predilection to metastasizing to bone. A dull ache or pain may bring this patient to a physician even prior to the time he has a pathologic fracture. This latter very often occurs at the site of a nutrient vessel in a long bone. It is almost always osteolytic in character and, at least at first, involves only a single bone. At least one-third of the cases with this type of tumor develop bone metastases, the most frequent sites being the humerus, spine, femur, ribs, or cranial bones. In numerous instances urograms may aid in the diagnosis. However, negative findings by urogram are repeatedly reported and it is only after a biopsy is done that we can make an accurate diagnosis.

Carcinoma of the Prostate

Metastases to bone from carcinoma of the prostate are frequent

FIGURE 465. *Left*, pathologic fracture of the femur. This followed metastases from carcinoma of the breast. *Right*, same case with femur immobilized by Küntscher nail. There is some evidence of repair.



FIGURE 466 Pathologic fracture of the neck of the femur. This followed metastases from carcinoma of the breast Fracture has been immobilized by a Smith-Petersen nail.

prostate, which so frequently metastasizes to the lumbar spine. Certainly orchidectomy plus the use of estrogenic hormones is indicated, because many of these lesions require a long period of care prior to pulmonary metastases and death.

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Carcinoma of the Prostate

Metastases to bone from carcinoma of the prostate are frequent

occurrences (Fig. 467). The bones most often involved are the pelvis and vertebral bodies in the lumbosacral area. Approximately 1 out of every 4 patients with prostatic carcinoma develop bone metastases. When one sees low back pain associated with nocturia or hematuria, one should suspect carcinoma of the prostate. In approximately 95 per cent of these patients a rectal examination reveals a stony, hard prostate gland.



FIGURE 467. Skeletal metastases from carcinoma of the prostate. This shows the definite glandular structure of the invading prostatic carcinoma while about this tumor tissue reactive bone can be seen. (From Geschickter and Copeland, *Tumors of Bone*, J. B. Lippincott Co.)

The roentgenologic features of this lesion simulate the lesions in Paget's disease, as the great majority of these lesions are osteoblastic in nature. There is a very small percentage which are osteolytic in nature.

In differentiating this lesion from Paget's disease, blood chemistry determinations are of considerable aid. In a very high percentage of

cases of prostatic carcinoma with skeletal metastases an elevation of the acid phosphatase occurs. This is not true of Paget's disease. In both instances the alkaline phosphatase may be increased. However, in metastases from prostatic carcinoma it is generally not as elevated as in Paget's disease.

Metastasis from other Organs

Carcinoma of the Thyroid. This tumor metastasizes to bone in a high percentage of cases, probably 1 out of 4. This involvement may be very late as indicated before.

Carcinoma of the Gastrointestinal Tract. In a very small percentage of cases, carcinoma of the gastrointestinal tract may metastasize to bone (between 1 and 3 per cent). The lesions may be osteoblastic, but in most instances are osteolytic.

Carcinoma of the Lung. In this lesion the ribs, spine, skull and sternum may be affected. Approximately 1 out of every 6 patients with carcinoma of the lung show bone metastases. The lesions are generally osteolytic. This type of tumor is becoming more and more common, at least in its diagnosis.

Carcinoma of the Female Genital Tract. *This may also be the source* of primary tumors which metastasize to bone. This type of involvement is extremely rare.

Hodgkin's Disease, Lymphosarcoma, and Leukemia

Lymphosarcoma and Hodgkin's disease have frequent bone metastases while leukemia very rarely does. At times these may simulate a primary or metastatic carcinomatous lesion. The vertebrae, pelvis and femora are the most frequent sites involved. Lesions may either be osteoblastic or osteolytic. In most instances there are no pathologic fractures and treatment is expectant and palliative in the form of roentgen therapy.

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17

Principles of Apparatus

TRACTION

There are several methods of producing traction upon a diseased joint or an injured extremity. The muscles surrounding these joints or extremities are in a state of reflex muscle spasm which represents Nature's effort to protect and restrain motion at the impaired joint or fractured bone ends. In the case of injury to the long bones, the surrounding muscles themselves may be severely traumatized at the time of the injury so that the movement of the jagged bone may increase the muscle irritation. This in itself may increase the degree of deformity present at the site of the fracture.

In considering traction upon a limb, it *must always be remembered that to be effective there must be countertraction.*

Fixed traction may be accomplished either by using *skin traction* with moleskin, adhesive plaster, Ace adherent or some similar medium, or by using *skeletal traction* in which the pull is made directly through and upon the bone. Elevating the foot of the bed for lower extremity injuries will allow the weight of the body to act as countertraction.

Skin Traction

With skin traction the pull is primarily effective upon the envelope of soft tissues surrounding the bone, and secondarily upon the bone itself, whereas with skeletal traction the reverse is true. One of the most satisfactory types of skin traction for *hip joint disease* consists in the use of two strips of moleskin plaster, long enough to reach from the hip to the foot of the patient and from 3 to 5 inches wide at the upper end and slightly less than that at the lower end, into which

is stitched a good strong buckle. The plaster is then divided into many tails as shown in Figure 468; the piece fitting on the outer side of the thigh should be 2 inches longer than the one fitting along the adductor or medial surface of the thigh and leg. The narrow strips are then



FIGURE 468. Moleskin plaster applied in crisscross manner with attached spreader, pulley and weights.

wound spirally around the leg from the ankle to the groin, each strip overlapping in a crisscross arrangement and continuing until the entire leg and thigh are well surrounded; care must be taken to leave both malleoli, the patella and the popliteal region of the knee uncovered. Below the foot a spreader is placed to prevent pressure against the malleoli, and then the whole leg is snugly bound with gauze bandage. This should remain in place until the adhesive is firmly attached to the skin. Then the desired weight can be attached.

When treating a *femoral shaft fracture* or a fracture of the hip in which skin traction is thought desirable, the adhesive should extend about 2 inches below the level of the fracture and traction should be applied immediately. Immediate heavy traction, decreasing the weight if the roentgenograms show dis-traction, is much better than starting with minimum traction and increasing the weights

When it is desirable to remove the traction temporarily to give physical therapy, foam rubber may be attached to the adhesive, these then being bound snugly to the extremity with an Ace bandage (Fig.

469). For many years it has been recognized that properly applied skin traction is an effective and simple method of lessening muscle spasm and relieving pain in diseased or injured bones and joints, but watchful care is necessary to avoid skin irritations. Painting the skin with tincture of benzoin just before applying the moleskin plaster is a protection against skin excoriation.

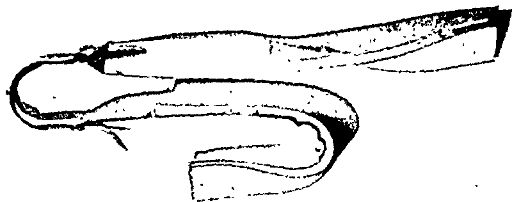


FIGURE 469. Foam rubber attached to moleskin. This method allows a removable type of traction to be applied and is useful when traction and daily physical therapy to the limb are both desirable.

Skeletal Traction

Skeletal traction is extensively used in the treatment of fresh fractures. This type of traction is frequently employed for fractures in both the upper or lower extremities. The lower end of the femur, the upper end of the tibia or the os calcis are the favored sites for application of skeletal traction in the lower extremity (Fig. 470). The Braun frame is employed to give suspension and traction. In fractures involving the humerus, the olecranon formerly was a favorite site to apply skeletal traction. Today the "hanging cast" and more careful reduction methods have lessened the need for skeletal traction in this region to a great extent.

When skeletal traction is used the skin should be locally anesthetized with procaine and the Kirschner wire or pin should be introduced through a nick in the skin under strict aseptic technic, a hand or motor drill being used for insertion of the wire. The best operating room technic should be insisted upon, for this is not an outpatient department or emergency clinic procedure. Care should be taken to prevent undue tension at the skin edge when traction is put on the pin. This may be

accomplished by using the finger to pull the skin upward before the wire or pin is inserted. A small cotton collodium dressing is placed about the entrance and emergence of the wire. The wire is then placed in the bow and tightened, and weights applied over the foot of the bed in the usual manner.

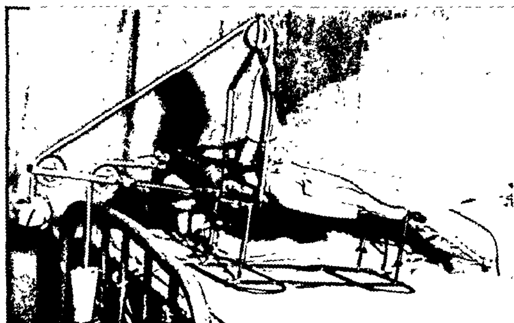


FIGURE 470 Skeletal traction through the os calcis for a comminuted tibial shaft fracture. The leg is suspended on a Braun frame.

If much weight is desired with traction in the lower extremities, elevation of the foot of the bed will utilize the body weight to produce countertraction and will help to prevent the patient from sliding to the foot of the bed. One side of the bed may be raised if the traction is being made laterally upon the arm. A foot piece should be used to prevent foot drop, or a light adhesive plaster sole piece made fast to an overhead rope (see Fig. 470) will prove very satisfactory.

When it becomes necessary to remove the Kirschner wire, no anesthesia is usually required; one end of the wire should be cut flush with the skin with a pair of sterilized wire cutters, and after painting the skin at that point with iodine or alcohol, the wire is withdrawn and a dry dressing applied for a few days

Balanced Traction

This method attempts to lessen the force of gravity and reduce friction of the limb against the bedclothes to the minimum It utilizes the overhead Balkan frame to suspend the limb. Often the foot of the bed

must be raised in order that the patient's own body weight may act as countertraction. Many different types of this traction-suspension apparatus are used. In all types, however, the ropes must run freely through the pulleys and the supporting part of the frame must be securely fixed. The most effective results of any traction are obtained with the patient in bed; in addition the great factor of rest can be utilized. Traction on a joint should always be in the line of deformity (see Fig. 470).

The use of a very ingenious and effective type of skin traction is demonstrated in Russell's traction (Fig. 471; see also Fig. 315), which

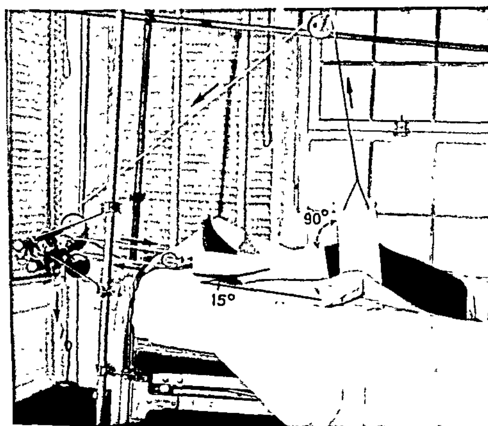


FIGURE 471. Russell's traction The ropes from the foot to the pulleys must be parallel. Proper angles which will produce a pulling force approximately twice the amount of the weights used are shown. With weights of 6 pounds, the pull on the femur is approximately 12 pounds.

is especially useful in femoral shaft fractures. It must be applied with due attention to detail.

Formerly the Roger Anderson, Haynes and Stader types of external fixation have been much used in the treatment of fractures and other conditions requiring rigid immobilization. In certain selected conditions they may be very desirable, but a good deal of experience is necessary

with each of these methods to obtain satisfactory results; in general, they do not supplant other open or closed methods generally in vogue.

Today the use of the plaster of Paris casing such as the "hanging cast" has simplified the treatment of humeral shaft fractures a great deal (Chapter 4).

PLASTER OF PARIS

It is said that the Egyptians thousands of years ago treated their fractures by means of linen stiffened with plaster. The present-day plaster bandage lends itself to so many varied uses in the treatment of bone and joint disabilities that every physician should be familiar with both its benefits and its dangers.

Composition. Plaster of Paris is crushed gypsum which is ground and heated in ovens at high temperatures, thereby being converted into an amorphous anhydride which possesses the power of recombining with water to form crystals. During the chemical union or the "setting" of the plaster it expands slightly, an important practical point, proving that plaster bandages do not shrink in drying. Also a certain amount of heat is normally produced by the chemical reaction, but this is not sufficient to cause discomfort to the patient. The time of setting can be accelerated by the addition of salt, whereas glycerin, molasses or glue retards the setting, however, these substances are rarely necessary with the good commercial grades of plaster available today. All bandage material should be of crinoline which has been sized with starch and not with glue. The meshes of the crinoline should be about 25 threads to the inch. The crinoline is cut into strips 3, 4, 5, etc., inches in width and into various lengths, and the edges are made deckle to avoid loose threads. The length for the smaller width bandages will be not over 3 yards while the wider bandages are rarely over 5 yards long. The best grade of dental plaster is firmly and evenly rubbed into these strips. They are then lightly rolled into bandages. The dental plaster should make up from 85 to 90 per cent of the total weight.

The bandage should not be rolled too tightly or it will not absorb the water evenly These bandages should be kept in a dry place, for if exposed to moisture they will deteriorate Today the physician will find it cheaper and more satisfactory to buy the carefully prepared commercial packages of plaster bandages directly from the supply houses. The "setting" time is printed on the box. The larger the plaster casing the longer the "setting" time should be.

Technic of Application. The patient's skin must be clean and free of all eruptions and skin irritations. As a rule the plaster is not applied directly to the skin but over a snug-fitting stockinet which may or may not be padded with adequate layers of sheet wadding. A skin-tight plaster casing should rarely be used in the treatment of fresh fractures because of the anticipated soft tissue swelling. After the swelling has subsided, usually in about ten days after trauma, a skin-tight plaster may be used if desired. No harm usually results by applying the plaster directly to the unbroken skin, provided the operator is familiar with plaster technic. However, it is somewhat more difficult to remove the casing without its layer of sheet wadding.

Very real danger of pressure sores or circulatory disturbances, even leading to gangrene, exists *in the employment of plaster casings, and* unless one is aware of these dangers and familiar with plaster of Paris the method should not be used. A safe method, but not a foolproof one, consists in padding the bony prominences, such as the anterior superior spine, the sacrum and the malleoli, with felt or several extra layers of sheet wadding to prevent pressure sores from developing.

After the bony prominences of the limb have been coverd by stockinet, sheet wadding and felt, the desired size of plaster bandage is placed on end within a pan of warm water around 70° F. and allowed to remain undisturbed until the bubbles have ceased to form. The operator then grasps the bandage, and, holding the palms over the ends, squeezes it with a gently twisting motion which brings out the majority of the water but does not allow the plaster to escape (Fig. 472). The bandage is applied evenly to the limb, care always being taken not to pull it tightly or to allow wrinkles to develop. *By careful rubbing of the successive layers of bandage as it is applied* one can obtain a smooth, homogeneous, snug but not tight-fitting plaster casing. "Reverses," "splints," or "reinforcements" can be made by an assistant at a table nearby (these are made by doubling one bandage back and forth on itself, smoothing each layer carefully), or the prepared "specialist" splints that have been dipped in the warm water can be used. The "reverse" is usually placed over the region of greatest stress and strain, i.e., the flexion creases, and extends longitudinally on the limb, being covered by subsequent layers of plaster bandages. They are placed on the posterior surface of the joint also, the aim being to permit the application of a light but strong casing. Other materials such as yucca or basswood splints soaked in warm water to make them pliable, or various types of rustless metal strips bent to

fit the contour of the part, can be incorporated in the plaster at the point of stress and strain in order to give stability and lightness. Care should be taken not to place a metal strip directly over the area subsequently to be x-rayed for this will effectively blot out the site.

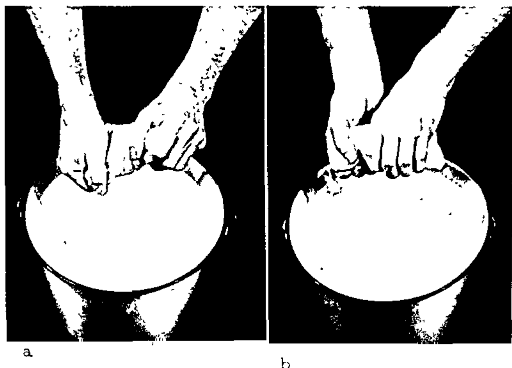


FIGURE 472. (*a*) The right way to wring plaster bandages. This retains the plaster in the bandage. (*b*) The wrong way, allowing the plaster to escape.

Bulky plasters that do not conform to the shape of the limb, and those which are applied unevenly without rubbing, are always a reflection upon the skill of the operator. It is quite surprising how light a plaster support can be applied if braced properly. To give comfort to the patient and a finished touch to the casing, the sheet wadding and stockinet should project slightly above the top and bottom of the plaster, so that they can be folded downward over the plaster to protect the skin from irritation. The final bandage is applied and one or two turns of plaster are wound around the edges, leaving uncovered a half inch cuff of sheet wadding and stockinet. The whole plaster is then polished by rubbing it thoroughly with an extra, wet plaster bandage.

Holding the limb during the application of the plaster in such a way that the desired position will be maintained is not always easy and requires more skill than does the application of the plaster. The

assistant should be warned against making finger impressions while holding the soft plaster; the palm instead of the fingers should be used. As the plaster hardens any surface indentations cause prominences and pressure against the limb or body inside the casing. The limb must be held or properly supported as long as the plaster is soft and not be allowed to rest on any flat, hard surface which will produce irregularities in the surface contour and give a chance for pressure sores to develop at that point on the skin.

If there has been any surgery or manipulation prior to the application of plaster, especial care must be taken to avoid tightness which may subsequently arise from soft tissue swelling within. The toes and fingers of the part must always be watched for any evidence of circulatory disturbance. Elevation of the part for the first few days after operation, using straps, pillows or blankets, lessens the tendency to severe swelling, but the dangers that exist in the use of plaster of Paris must be constantly recalled to doctors, students and nurses. *Persistent postoperative pain following application of a plaster casing should always be investigated early;* splitting of the casing may be necessary.

Trimming the Plaster. This is most satisfactorily done before the patient leaves the operating room, as at that time the plaster has not thoroughly hardened and can easily and accurately be trimmed with the use of a Bard-Parker knife, or one of the various types of plaster knives on the market. There is a tendency to trim plaster spicas, or similar bandages, in such a way that too much plaster is cut, allowing inadequate support to the part. The plaster in the groin and sacrum should be cut only enough to permit cleanliness but not enough to allow a large portion of the buttocks to bulge out under the edge of the plaster on the affected side. At the toes, the tip and nail of each toe should be seen, but as a rule the plaster should be trimmed only slightly proximal to the base of the nails. Over the sole of the foot the edge of the casing should project slightly beyond the tips of the toes (Fig. 473). This will protect the toes when the patient is resting on his abdomen. The average plaster should be hardened, but not dry, 6 or 8 minutes after its application; the operator can profitably spend this interval in rubbing and smoothing the body contour of the plaster casing.

Care must be taken in moving patients wearing large spicas at the shoulder or hip from the operating room to the bed. Rough handling or unusual strain causes the plaster to break at the body-flexion creases.

fit the contour of the part, can be incorporated in the plaster at the point of stress and strain in order to give stability and lightness. Care should be taken not to place a metal strip directly over the area subsequently to be x-rayed for this will effectively blot out the site.

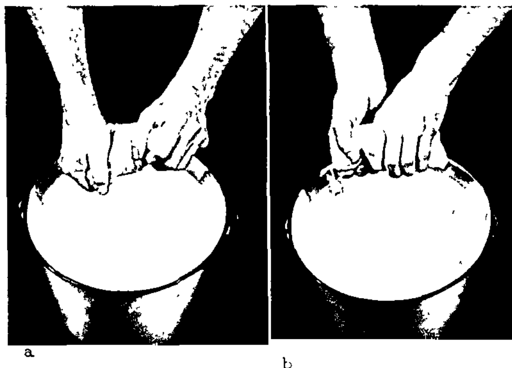


FIGURE 472. (*a*) The right way to wring plaster bandages. This retains the plaster in the bandage (*b*) The wrong way, allowing the plaster to escape.

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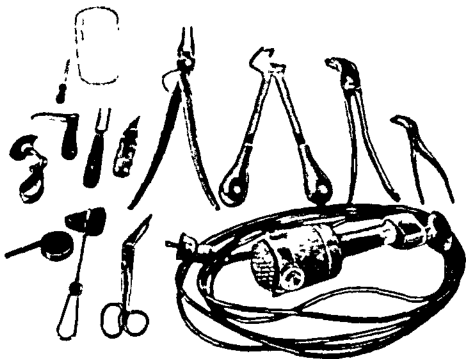


FIGURE 474. Instruments used for cutting and spreading plaster of Paris casings, plus tape measure, percussion hammer and scissors.

All patients must return to the doctor at the first sign of discomfort in plaster and they should always:

(1) Observe whether or not the plaster feels too tight or is persistently painful. If so, longitudinal splitting of the plaster casing is done.

(2) Inspect the toes or fingers projecting from an applied plaster casing frequently; look for swelling, blueness and numbness.

(3) Look for softening and cracking in the plaster, especially at the flexion creases.

(4) Watch for any evidence of skin irritation about the upper or lower edge of the plaster.

(5) Check daily as to whether any odor of the plaster is present.

CRUTCHES

Adjustable crutches are an indispensable aid in the care of the cripple but they must be of the necessary length and used properly. At present wood or duralumin is in general use, but probably some satisfactory plastic material will soon be developed. In order to obtain proper support, the weight of the patient should be carried with the h resting on the handles of the crutches rather than by the p

The plaster completely dries rather slowly, but this may be hastened by having it exposed to the air. In some hospitals a plaster dryer is available and may be employed after the patient leaves the operating room.



FIGURE 473 The proper method of trimming plaster. When the patient is turned on his face, the projecting plaster protects the toes.

Removal of Plaster Casts. In the removal of plaster casts the Stille's plaster cutter is satisfactory. Various types of electrical saws and various modifications of the plaster cutters have been devised, one of the best being the Stryker electric plaster saw. A good, strong plaster knife, aided by the frequent application of tap water dripped on by a small rubber syringe to soften the plaster and by "elbow grease," will in time permit the thickest plaster to be safely removed. A plaster spreader is very useful in spreading apart the cut edges of the plaster casing. For cutting small windows in the plaster or trimming the edges an electric saw is a most satisfactory time-saver. However, if this is not available hydrogen peroxide or vinegar dripped on the area to be cut softens the plaster more quickly than plain water (Fig. 474).

Rules to Be Observed by the Patient Wearing a Plaster Cast. It has been found useful to give the following rules to every patient wearing a plaster cast, or to the parent or guardian.

In measuring for crutch length, the distance from the axilla to a point on the floor 8 inches from the side of the body is taken. The patient should be wearing shoes and the hand grip should allow the elbow to be slightly flexed so the weight can be largely borne by the hands.

ORTHOPAEDIC APPLIANCES

Details of the use and fitting of orthopaedic appliances are less familiar to the present-day student of orthopaedic surgery than formerly. This is due somewhat to the lack of interest shown by the orthopaedic surgeons in this subject, as well as to the increased knowledge various large manufacturers and brace makers have shown in selling their products. This is unfortunate, since both instructions regarding the type of mechanical support required and the actual fitting should logically be in the hands of the orthopaedic surgeon. He should be trained to recognize the appliance necessary for the individual problem. The good brace maker needs skill and experience in order to fulfill the physician's prescriptions, but the most satisfactory arrangement is a thorough co-operation and understanding between the orthopaedic surgeon and the brace maker.

Stainless steel is preferred to surgical steel or duralumin in the construction of braces because the latter have a tendency to break. Stainless steel is initially somewhat more expensive but since it does not rust, its cost is eventually equal to that of surgical steel. Possibly some plastic material will soon be found that is preferable to stainless steel.

When leather is needed to cover certain portions of a brace either elk skin or a good grade of strap leather should be used. It pays to use a good grade of leather. With all appliances the patient should have a card of directions somewhat as follows: (1) Keep braces clean and oil joints often. (2) Keep heels and soles of shoes repaired. (3) Do not abuse brace. Hard exercise generally should not be done. (4) Do not delay repairing brace when it becomes broken.

When a patient is bedfast, a support is often applied in order to restrain movement and to hold the part in the desired position. This means that splints made of plaster, duralumin or other material will give adequate support and rest. When the patient becomes ambulatory, a brace to withstand the stress and strain of weight bearing and yet maintain the part in the desired position is necessary, *but braces are primarily designed for support and immobilization and not for the correction of deformity.* Generally speaking, the correction of a de-

ting pressure on the axillae. The danger from pressure against the axillae is very real; pressure by the prolonged use of inadequately padded or improperly used crutches may cause a crutch palsy involving the muscles supplied by the radial nerve. In cases with severe brachial plexus pressure there may be complete wrist drop. Although the prognosis for recovery is very good, wrist drop may prohibit use of the crutches for a considerable period of time. Crutches should always be padded with rubber at the axilla, handles and on the ends, preferably using a good suction tip. Adjustable hand bars are at times very useful.

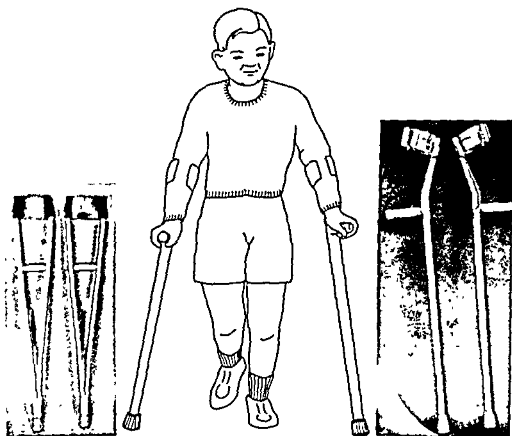


FIGURE 475. Canadian crutches Two types are shown in the photographs. Center figure shows how body weight is borne by hands.

The Canadian type of crutch may be of wood or light metal and prevents axillar pressure, the weight being borne on the hands with the forearm cuff as shown in Figure 475. These shorter crutches are lighter and are preferred for those who are not badly paralyzed. However, they have some definite drawbacks for those severely paralyzed, such as not acting as a supporting medium when the patient wishes to open a door or brace himself against sudden jars.

but it may be difficult to control the activity of the patient without restraining straps. A child may be held on the frame by means of a canvas belt over the abdomen and axillary straps about the shoulders, or by the use of the Carrell metal frame which is attached to the Bradford or Whitman frame (Fig. 476).

If traction is desired, head traction can be employed in the usual way (see Fig. 124). A certain degree of both traction and immobilization of the spine is secured by the use of head traction or by applying a wide swathe of canvas to the pelvis about the crests of the ilium and making traction over the foot of the bed (pelvic traction) (Fig. 477). A useful method for caring for injuries to the pelvic ring is by suspension in a canvas hammock (Fig. 478).

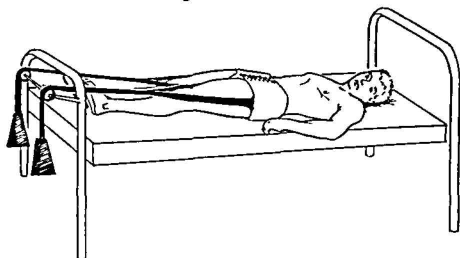


FIGURE 477. Pelvic traction This is occasionally more effective than Buck's extension in relieving acute lumbosacral strain.

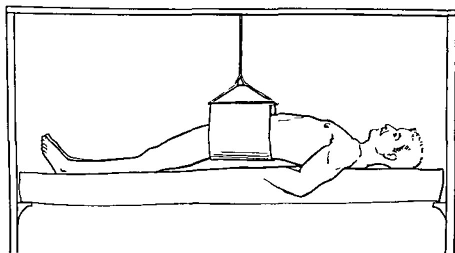


FIGURE 478. Suspension of pelvis in canvas hammock Useful for pelvic injuries (see p. 473).

formity should be accomplished before the brace is fitted and before the patient becomes ambulatory.

Back Supports

When Recumbent. For the recumbent patient, one of the most useful types of support to the spine is the *Bradford frame,* which consists of a rectangular frame of gas pipe, a few inches longer than the patient and slightly wider than the patient's pelvis, with a canvas cover drawn tightly over it. Straps or rope act as a lacing on the undersurface of the frame, leaving a space at the buttock area for the use of the bed pan.

A modification of this is the *Whitman frame,* designed for the correction of deformity by bending it to the desired degree of convexity. This is smaller and lighter than the Bradford frame and should be about 4 inches longer than the child and about four-fifths as wide. This frame is also covered by canvas suitably protected in the center by a rubber cloth and two thick felt pads about 7 inches in length and 1 inch in thickness which are sewed to the frame. These pads are placed on each side of the spinous processes at the site of the spinal disability in order to increase slightly the leverage of extension and to secure firmer fixation to the affected part when the spine is in the extended or slightly convex position. The Bradford or Whitman frame not only permits relaxation of the spinal muscles but tends to enlarge the rib cage and increase the patient's vital capacity.

Various types of back frames have been devised which permit the support gradually to be made concave or convex by a turnbuckle attachment. Convexity of the spine, if desired, can be easily obtained,

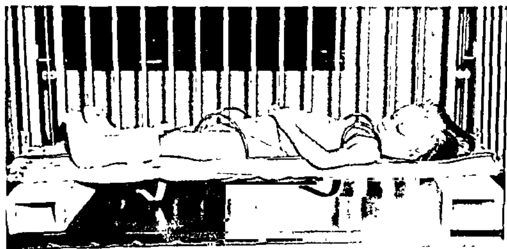


FIGURE 476. The Carrell frame attached to the Bradford frame. It is hinged at the head and held with a bolt between the thighs, allowing the patient to have controlled motion, but remain recumbent.

For the type of back disability that needs greater stability and support, a *plaster jacket* (Fig. 480) can be applied, using a minimum of padding but covering bony prominences with strips of felt. These plaster jackets may be split down the front after hardening. Hooks and eyes or zippers can be applied in order to make them removable.

The Calot plaster jacket (Fig. 481) is essentially a plaster jacket giving fixation to the spine, head and neck, and some direct pressure over the spine. It was primarily used by Calot for tuberculous disease above the tenth dorsal vertebra. It is difficult to apply and adjust, but is more effective than any other ambulatory support for cervical and high dorsal disabilities.



FIGURE 480. Plaster of Paris jacket. This may be split in front and lacing applied if temporary removal is desired. This is a very cheap and efficient support.

A celluloid jacket (Fig. 482) gives support and immobilization but is much more expensive than a plaster jacket and requires that a mold of the body be made. A mold is made by applying a plaster jacket to the body. This is then split down the front, removed from the patient and filled with a casting grade of plaster. After this is thoroughly set,

In patients thus treated, the back, particularly in the sacral region, should be daily observed for evidence of skin pressure. A slight shifting of the body from side to side or a small air ring placed under the sacrum may prevent serious pressure sores from developing.

When Ambulatory. The essential features of the *canvas back support* (Fig. 479) used for low back pain or sacroiliac strain are the

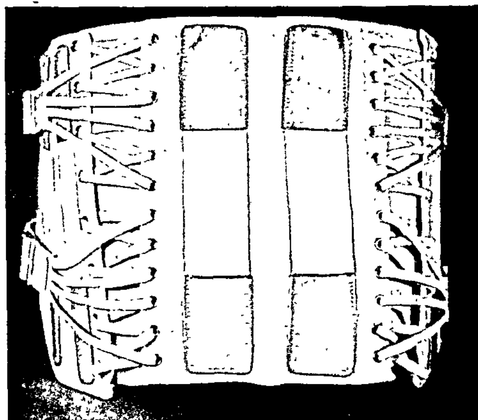


FIGURE 479. The "University" support. This is a light canvas belt for chronic lumbosacral strains. Perineal (groin) straps may sometimes be added and vertical steel strips bent to the contour of the back are added.

abdominal apron, which should be wide enough to give adequate abdominal support, and a reinforcement for the back consisting of double layers of canvas, with light steel or featherbones shaped to fit the lordotic curve snugly. The support has laces or straps either in front or on the side, never in the back. It should be secured snugly about the pelvis, being reinforced by a belt or straps between the tip of the greater trochanter and the crest of the ilium. Because of the tendency for back supports to slide upward, groin straps attached to the front and back of the support may be used to keep it in place. When used for the female patient, garters attached to the back support prevent it from slipping up.



FIGURE 482. Celluloid jacket. Lighter and cooler but more expensive than plaster, it is made over a body mold of the patient.

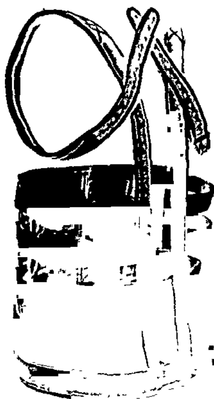


FIGURE 483. Taylor spinal brace. A wide or narrow abdominal apron may be attached.

the outer shell or casing is removed and the celluloid jacket is built by tightly applying successive layers of stockinet. Each successive layer of stockinet is painted by using a brush and a mixture of celluloid dissolved in acetone or Dupont "dope." Leather types of jackets must be built on a mold also, but are not frequently used because of the expense involved.

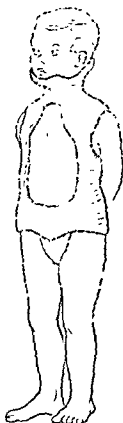


FIGURE 481. Calot plaster jacket This is intended to be applied to the spine only when the pathologic condition is above the tenth dorsal vertebra.

Back braces are many types and are named after the individuals most instrumental in originating them. Essentially the back brace consists of two parallel steel bars applied on each side of the spinous processes with a pelvic band of metal from 1½ to 2 inches in width and long enough to reach from one anterior superior spine to the other. The pelvic band, or base portion, is placed as low on the pelvis as possible, just above the tip of the trochanters, and to this the uprights are firmly attached. In the *Taylor spinal brace* (Fig. 483) the uprights reach up to the root of the neck or about the level of the second dorsal vertebra, and padded shoulder straps are applied which pass about the axilla and attach to a crossbar on the back brace. The parellel back bars should not be high enough to cause downward pressure on the



FIGURE 485. Celluloid cervical collar. This type of collar is light and comfortable. It should be made from a mold of the patient.

The *cervical collar* consists of metal pieces covered with leather, or it can be made with celluloid (Fig. 485), but in any instance a mold of the head, neck and shoulders must be obtained first. However, a satisfactory adjustable cervical collar (Fig. 486) can now be purchased from brace manufacturers. A temporary and fairly effective cervical support can be made in a few minutes using cardboard, felt and stockinet. This will give support and protection to the neck during the interval when a permanent brace is being made but gives no dis-traction.

Lower Extremity Appliances

When Recumbent. Supports to the lower extremities may be made of plaster or, in certain instances, stainless steel or commercial duralumin, all of which are satisfactory. Two important factors are to be borne in mind in employing these temporary splints: (1) A crossbar at the ankle region at right angles to the long axis should be incorporated to prevent limb rotation, and (2) the foot should be kept at right angles to the leg.

The *Thomas splint* is probably the most important and valuable

shoulders. Pressure pads were originally made of felt, leather or hard rubber which produced firm and constant pressure at the seat of the spine disease, and this type of brace was intended to support and immobilize the entire dorsal and lumbar spine.

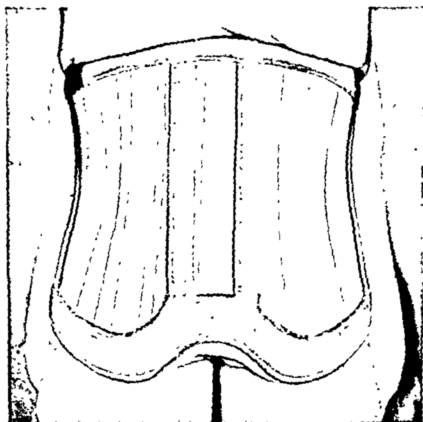


FIGURE 484. Knight spinal brace with butterfly wings forming the base.

The *Knight spinal brace* (Fig. 484) does not have shoulder pieces and was devised to give support and fixation largely to the lower thoracic and lumbar spine. All of these back braces are fitted with a wide abdominal belt for support.

The low back brace is a useful light support modified from the original Knight brace. If support is needed over the sacroiliac region, butterfly extensions are added, and sometimes canvas is snugly fitted to the lateral upright steel bars as well as to the abdominal apron to give a further bandaging effect. Braces with attached crutches, fitting in the axillae, are rarely desirable

The *Hoke type* of canvas back support is particularly useful in patients needing muscle bracing, as in those having paralytic spinal curvature. It can be fitted closely to the body, being reinforced by feather bone and light steel stays.

angle of the scapula to the middle of the calf posteriorly, which was fitted to the body of the patient and held in place by chest, thigh and leg bands. This splint is not much used today and few brace makers know how to construct it.

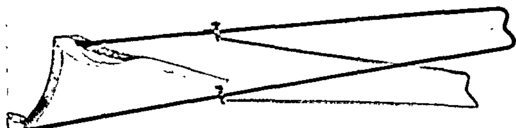


FIGURE 487. Half-ring Thomas splint with Pearson attachment.



FIGURE 488. Half-ring Thomas knee splint with an extension for weight bearing. This permits the weight to be borne on the ischium rather than on the hip or knee joint.

The *Taylor traction hip splint* consists of a horizontal pelvic band and long lateral bars. The upright on the outside of the leg is shaped to the leg's contour and at the bottom the upright is turned inward to

splint because of its effectiveness and the multiplicity of its uses. It consists essentially of two round iron rods which are joined at the upper end with an oval ring of the same metal; its lower end is bent to form roughly the letter "W," in order that the rope producing traction on the



FIGURE 486. Adjustable cervical collar. This supplies the necessary rigidity and dis-traction can be obtained, making it useful in certain cases of cervical arthritis.

foot may be easily attached to the brace. It should be made of rigid, unyielding iron and not steel, and the angle between the inner side of the ring and the inner bar should be 120 degrees, whereas that between the outer bar and the outer portion of the ring should vary with the size of the splint. The ring is padded with felt and covered with smooth, firmly stretched leather. Since pressure is carried on the inner and posterior margins of the ring, the felt is thicker at that part The half-ring type of this splint is also much used because of its ease of application. To either of these splints, the Hodgen or Pearson attachment, which permits controlled knee motion, is often applied (Fig. 487).

When Ambulatory. The original *Hugh Owen Thomas hip splint* consisted of a flat piece of malleable iron extending from the lower

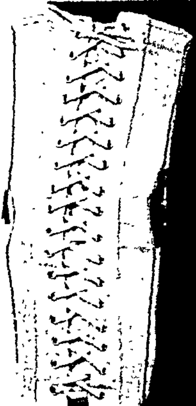


FIGURE 490. Light type of knee cage.

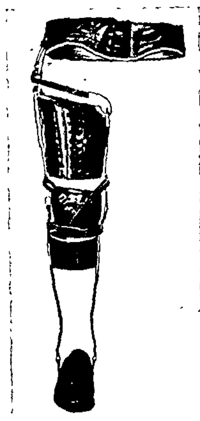


FIGURE 491. Long leg brace with pelvic band, a lock at the knee and free motion at the ankle. The brace is attached to the shoes, motion being at the level of the ankle joint.

form a right angle constituting the bottom piece of the splint, so that traction can be made on the lower extremity by means of a windlass. To the windlass is attached the adhesive strapping which is placed on the lower extremity; thus definite traction downward is obtained while

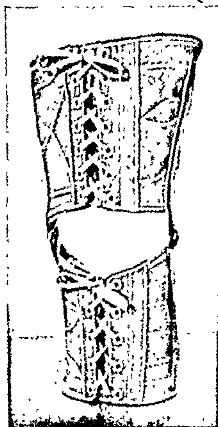


FIGURE 489. Jones type of knee cage, which permits a controlled number of degrees of angulation at the joint.

the patient is ambulatory. Owing to the increased surgical treatment of hip joint disease, the Taylor traction hip splint is rarely used today.

The *Thomas knee splint* (Fig. 488) is very useful. If the patient is ambulatory, he literally sits within the pelvic ring, the weight being transmitted from the foot piece to the tuberosity of the ischium. If the brace is made 2 or 3 inches longer than the limb of the unaffected side and the shoe on the sound side is elevated the requisite amount, the patient bears the minimum amount of weight on the affected knee joint or hip joint.

The *Jones knee cage* (Fig. 489) also is useful in giving stability to the knee joint and may have a dial-joint wheel applied to permit motion only in a definite arc. This may be decreased or increased as desired. Several lighter types which can be molded to the thigh and leg are shown (Figs. 490–492).

which can be attached to the ordinary shoe, can be made. The patten is usually made of cork or balsa wood because of their lightness.



FIGURE 493. Short leg brace with free, limited or no motion at the ankle joint. This brace is useful in many paralytic conditions.

This method is sometimes desired because an ordinary shoe can be used (Fig. 495).

Upper Extremity Appliances

In the upper extremity, appliances can be used whether the patient is ambulatory or not.

The *abduction or airplane splint* (Fig. 496) at the shoulder holds the upper extremity at approximately a right angle to the body and slightly anterior to the body plane. The *half-ring Jones abduction arm splint* is an efficient splint for certain fractures of the upper end of the humerus, but must be fitted so that the elbow will be held slightly in front of the coronal plane of the body. A strap over the opposite shoulder and two straps around the body hold it snugly in place.

The *elbow splint and the wrist, hand and forearm splints* can be individually made of plaster of Paris or aluminum, or various types of

The *caliper brace* (the full-length leg brace, or short leg brace with one or two bars) is useful in paralytic conditions, and the double long upright brace may be with or without pelvic band (Figs. 491 and 492), depending upon the amount of active power in the rotators of



FIGURE 492 Long leg brace without pelvic band, a lock at the knee and free motion at the ankle The brace fits into a slot in the heel of the shoe, motion being below the ankle joint proper.

the hip. At the knee and ankle there can be a free, limited or no-motion joint as the individual case requires.

The *short leg brace* (Fig. 493) is useful in those patients requiring support owing to a disability about the ankle and foot. The wire spring drop foot brace is a light type attached to a shoe, as shown in Figure 494, and is very useful for temporary weakness of dorsiflexors of the foot.

The *clubfoot type of brace*, on the other hand, has a very limited degree of usefulness Any clubfoot, if adequately corrected in plaster, usually will not need any form of support other than that afforded by slight modifications in the shoes

The use of a patten Occasionally a patient may refuse operative correction on a short lower extremity and then a simple type of patten,



FIGURE 496. A satisfactory airplane splint can be made of heavy wire, properly covered and padded. Note that there is a strap over the opposite shoulder and that the lower band rests on the pelvis, both assuring stability.

plastic splints such as lucite are available. Circular plaster of Paris can be applied to the part and then made bivalvular, after which the posterior section can be removed, dried in an oven, properly padded with felt and fitted with shoulder straps. This gives one of the most satisfactory and snug-fitting types of upper extremity splints.

Various types of ingenious wrist and finger splints introduced by Dr. Bunnell (1956) are shown in Figures 497 to 500 to illustrate active splinting in contradistinction to passive splinting.

References

1. Bunnell, Sterling. *Surgery of the Hand* (3rd ed). Philadelphia: J. B. Lippincott Co., 1956.
2. Edwards, J. W. *Orthopaedic Appliances Atlas.* Ann Arbor, Mich., 1952.
3. Russell, R. Hamilton. *Brit. J. Surg.*, 9:491, 1923–24.

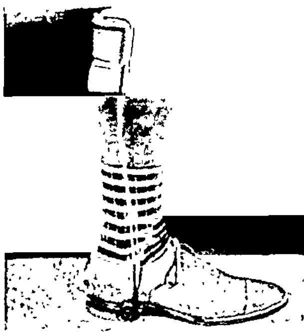


FIGURE 494. A very light and effective type of drop foot brace.

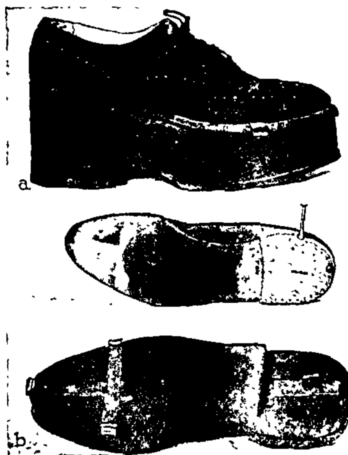
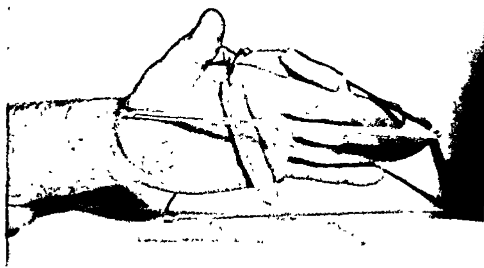


FIGURE 495. A useful method of equalizing severe limb shortening. The patten is attached securely to an ordinary shoe and if made of cork or balsa wood is light in weight.



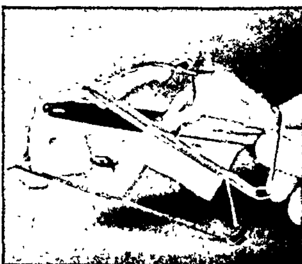
FIGURE 498. Spring cockup splints, made of flat blued spring, size 0.045 × 5/8 inch, or of a loop of piano wire, size 0.015 inch. This splint gradually persuades the wrist to assume a position of dorsiflexion. An oblique strap (*x*) through the chamber in the neckpiece and looped over produces (*upper*) dorsiflexion and (*lower*) flexion. (From Bunnell, *Surgery of the Hand*, J B. Lippincott Co.)



A



B



C

FIGURE 497. (*A*) Knuckle bender splint to draw proximal finger joints into flexion. This light, simple splint carries the motion through. There are three points of pressure, well padded and motivated by rubber bands. (*B*) *Lower*, proximal finger joints extended; *upper*, proximal finger joints drawn into flexion. Note that placing rubber on back of thumb draws it into opposition. A leather loop on a rubber band over the rear hook will draw the thumb firmly into opposition. (*C*) Holding splint open with fountain pen. (From Bunnell, *Surgery of the Hand*, J. B. Lippincott Co.)



FIGURE 500. Combination knuckle bender and Oppenheimer splint with attachment to flex middle finger joints. Purpose: To place hand in position of function, to dorsiflex wrist, to flex proximal and middle finger joints and to oppose thumb. The Oppenheimer splint and that to flex the middle finger joints are made to attach to the knuckle bender. (From Bunnell, *Surgery of the Hand*, 3rd ed., J. B. Lippincott Co.)

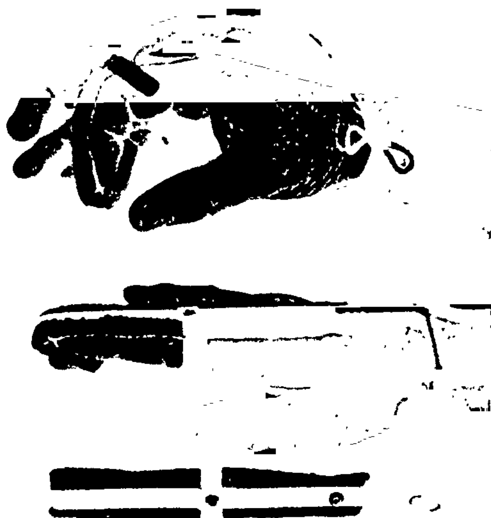


FIGURE 499. Clock spring splint to extend the finger gradually. Size 0 02 × 16/64 inch. *Upper*, flexion; *lower*, extension. (From Bunnell, *Surgery of the Hand*, J. B. Lippincott Co.)

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NOTE: Most adjective-noun combinations (e.g., vertebral epiphysitis) are listed under the noun.